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Technical Article

Environmental performance of feed production for broiler in Piauí state, Brazil

Desempenho ambiental da produção de ração para frango de corte no Piauí

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ABSTRACT

This study aimed to identify and evaluate the potential impacts of feed production for broiler poultry, using the life cycle assessment methodology. Primary data collection was conducted in a poultry cooperative of Teresina, Piauí state, Brazil, and involved the identification of raw materials, as well as their origin and quantity, and the stages of the production process. In addition, we used secondary data from the Ecoinvent database, available in SimaPro software, in which the modeling was performed. The ReCiPe Midpoint (H) was used as the evaluation method. The characterization of the impact assessment showed that the greatest impacts are related to the use of ingredients with high energy and protein content, such as maize and soybeans. This is due to the negative environmental impacts associated with the agricultural production of these materials (Ecoinvent data), as well as the transport between the farms (Uruçuí and Sebastião Leal, Southern Piauí) and the feed factory (approximately 520 km away from Teresina). Thus, these impacts are associated with activities outside the cooperative boundaries. Furthermore, the use of meat and bone meal, a by-product originated from abattoirs, determined the appearance of positive environmental impacts in all categories of the used method, especially: eutrophication of freshwater bodies, marine ecotoxicity and ozone layer depletion. The reuse of these by-products (meat and bone meal) is environmentally advantageous.

Keywords: feed production; broiler; life cycle assessment; environmental impact.

RESUMO

Este trabalho teve como objetivos identificar e avaliar os potenciais impactos da produção de ração para frango de corte com a metodologia de avaliação do ciclo de vida. A coleta de dados primários foi realizada em uma cooperativa de avicultores de Teresina (PI) e envolveu a identificação das matérias-primas, além de sua origem e quantidade, e de etapas do processo produtivo. Também, foram utilizados dados secundários do banco de dados Ecoinvent, disponível no *software* SimaPro, com o qual foi executada a modelagem do processo, pela qual identificamos as entradas e saídas do sistema. O método de avaliação usado foi o ReCiPe Midpoind (H). A caracterização da avaliação de impacto mostrou que os impactos mais significativos estão relacionados à utilização de ingredientes com maior teor de energia e proteína, como milho e soja. Isso se dá em razão dos impactos ambientais negativos associados à produção agrícola desses materiais (dados do Ecoinvent), além do seu transporte entre as fazendas (Uruçuí e Sebastião Leal, região sul do Piauí) e a fábrica de ração (a aproximadamente 520 km de distância de Teresina). Desse modo, são impactos ligados às atividades que ocorrem fora dos limites da cooperativa. Além disso, a utilização da farinha feita com carne e ossos, subproduto oriundo de abatedouros, determinou o aparecimento de impactos ambientais positivos em todas as categorias do método utilizado, com destaque para: eutrofização de corpos de água doce, ecotoxicidade marinha e depleção da camada de ozônio. O reaproveitamento desses subprodutos (farinha feita com carne e ossos) é ambientalmente vantajoso.

Palavras-chave: produção de ração; frango de corte; avaliação do ciclo de vida; impacto ambiental.

INTRODUCTION

Poultry is present all over the world, and its world production in 2015 was about 87 million tons. When analyzing the poultry industry in Brazil, there are high growth rates, reaching 13.14 million tons in 2015. Brazil is the second largest producer of poultry in the world, and in 2004 even went on to lead exports for the poultry sector (ABPA, 2016). of the Brazilian poultry production, 67.3% is destined for the domestic market and 32.7% for exports. In terms of consumption, in 2014, the country's poultry consumption per capita was 42.78 kg.hab^{-1} (ABPA, 2016).

Due to this scenario, it is emphasized that the increase in poultry production raises the demand for feed. The production of feed ingredients,

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the transport of these ingredients, and the production process in feed mills consume natural resources and release CO_2 emissions into the atmosphere, as well as interfere with water and soil quality and biodiversity. This impacts several categories of environmental indicators, such as climate change, depletion of the ozone layer, eutrophication, etc. (TONGPOOL *et al.*, 2012).

In this sense, food production represents a great challenge for global sustainability in the 21st century (BENGTSSON & SEDDON, 2013), because, on the one hand, there is the search for productions that meet the population's needs and, on the other, there is a need to care for environmental protection.

In order to establish reliable environmental criteria for food products and animal feed, Ruviaro *et al.* (2012) defend the Life Cycle Assessment (LCA) methodology for agribusiness, in order to contribute to decision-making actions on the performance of productive agriculture, its technologies, and the processes derived from the organization or systematization of production.

Under this approach, Roy *et al.* (2009) admit that the environmental consequence influences how companies and government agencies guide the development strategies and interests of food production systems.

It can also be pointed out that, in quantifying the environmental impacts of food products, LCA is one of the most accepted international methods (ROY *et al.*, 2009), as it assesses the potential impacts of a product/process/service throughout its life cycle, that is, from obtaining the raw material, through all stages of production, transportation and use, to final disposal or re-use (ABNT, 2009a).

Faced with this context, issues such as quality of production, health, and the environment, among others, are constantly raised in the area's literature. After all, it is understood that agricultural production must be in line with the principles of sustainability. In this respect, Garnett (2014) emphasizes that, in order to obtain perspectives for achieving sustainability in the food system, the use of LCA helps to strengthen the efficiency mentality in food production.

In the LCA studies, several environmental impact categories (eutrophication, climatic changes, water depletion and occupation of arable land, among others) can be used to express the contribution of each phase/process (TONGPOOL *et al.*, 2012; NGUYEN *et al.*, 2012; GOEDKOOP *et al.*, 2013).

The extent to which the LCA deals with environmental issues - not in a timely manner, but rather with a holistic view - prevents that a given problem changes from one phase of the life cycle to another. Furthermore, such methodology is recognized as the best available to investigate the performance of environmental sustainability in a reliable and transparent way and, therefore, is able to communicate in a safe and comprehensive manner (BAITZ *et al.*, 2013; BENGTSSON & SEDDON, 2013). In addition, the use of various mathematical models to address all environmental aspects of their respective environmental impacts also reduces uncertainty in decision-making among the different options (CHERUBINI *et al.*, 2015).

Silva *et al.* (2014), in a study on poultry production, state that the greatest negative environmental impacts are present in the feed production phase, and that LCA is an adequate tool for the overall analysis of the entire poultry production chain. Therefore, they emphasize the importance of regional studies using the LCA that involve Brazilian maize or soybean.

Thus, this study aimed to evaluate the potential impacts of broiler feed production in different formulations that consider the life stage of the chicken, with the use of LCA.

METHODOLOGY

For the evaluation of the environmental impacts, the present study was based on the Brazilian Standards (NBR) of the Brazilian Association of Technical Standards (ABNT, 2009a; 2009b), on life cycle assessment, and on the software SimaPro version PhD 8.0.3.14 (PRE CONSULTANTS, 2014).

The scope of this investigation covered the production of ingredients (maize, soybean, soymeal and meat and bone meal), land transportation (road modal) of the ingredients to the feed mill and the production process in the factory (Figure 1).

For the calculation of the emissions from the transport of the ingredients, the distance from where the inputs are produced to the feed mill was considered (Table 1).

The functional unit (FU) considered was 1 kg of processed feed for broiler.

The nutritional requirements of broiler depend, among other factors, on the stage in which it is found. In this study, the following phases were evaluated: pre-initial (1 to 7 days); initial (8 to 21 days); growth I (22 to 33 days); growth II (34 to 42 days); and final (43 to 46 days) (ROSTAGNO *et al.*, 2011).

Life Cycle Inventory

The Life Cycle Inventory (LCI) data were obtained through visits to the feed mill between 2014 and 2015, which allowed the knowledge of the entire production process and the construction of a flowchart that portrayed the various steps from the obtainment of raw material, in addition to its origin and quantity, to the final product, which is the finished feed. Also, it was possible to know the inventory of machines with their respective powers and time of use. Secondary data were also obtained from the Swiss Center of Life Cycle Inventories (Ecoinvent 3) and U.S. Life Cycle Inventory Database (USLCI) libraries, which are available in the SimaPro PhD 8.0.3.14 software database (PRE CONSULTANTS, 2014).

Agricultural production

The feed ingredients, such as soybeans and maize, were produced in the state of Piauí, specifically in the state's *Cerrado*, whose area is 93,424 km^2. The soybean meal used in the factory is processed at Bunge Alimentos, located in the municipality of Uruçuí (PI).

Currently, the soybean and maize producing region in question is part of Matopiba, created through Decree No. 8,477, dated May 6, 2015, to represent areas of high agricultural productivity in the states of Maranhão, Tocantins, Piauí, and Bahia (BRASIL, 2015).

Regarding data on soybean maize corn production and emission, the average annual production in one hectare of a typical Brazilian farm was examined. The limits of the system went from gate to gate of the farm, and all the direct inputs and emissions associated to the respective productions were covered (fertilizer use, fuel use for field operations, field emissions to air and water, emissions due to the use of pesticides and changes in the use of land).

The electricity considered in the feed mill's production process was high voltage, produced in Brazil, which includes: transmission network, direct emissions to the air (ozone and N_2O) and energy losses during transmission.

Feed composition

In the feed composition of broilers, the Brazilian formulations are based on macro-ingredients (maize, extruded soybean, and soybean meal) as a source of energy and protein. This study took into account the percentages of Table 2.

Allocation procedures

To obtain the soybean meal, the soybean meal and oil meal were allocated by mass (soybean meal 82% and 18% oil).

Table 1 – Origin of the main inputs used in the manufacture of feed.

Ingredient	Municipality of origin	Distance (km)
Maize	Uruçuí (PI)	583.0
Soy	Sebastião Leal e Uruçuí (PI)	453.6
Soybean meal	Uruçuí (PI)	457.0
Meat and bone meal	Timon (MA)	18.5

Table 2 – Composition of macro-ingredients by feed formulation

Macro-ingredient	Pre-initial	Initial	Growth I	Growth II	Final
Maize (%)	61.73	59.86	64.56	64.57	67.43
Extruded soybean (%)	5.00	22.20	22.35	27.10	23.55
Soybean meal (%)	26.20	11.00	6.40	1.55	2.90

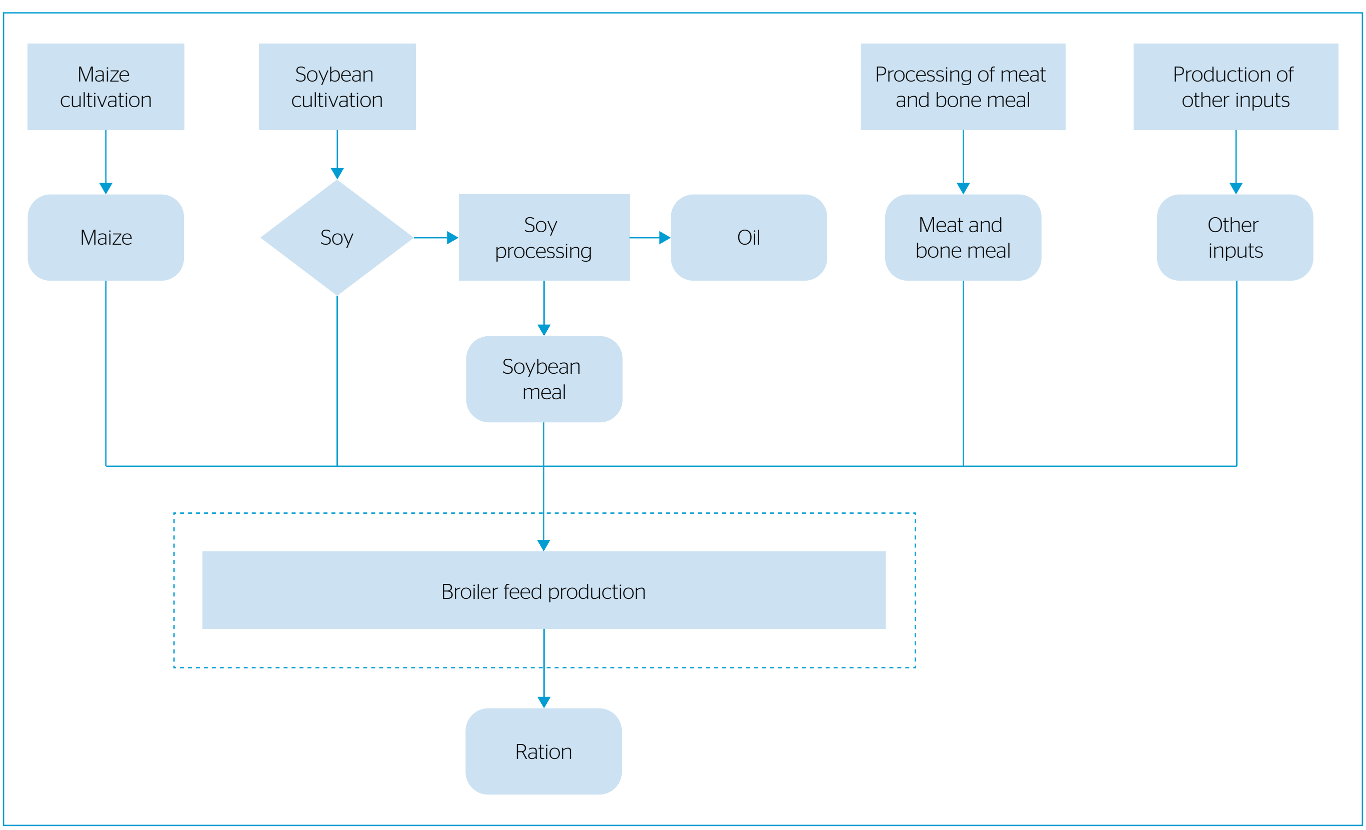

Figure 1 – Simplified flowchart of broiler feed production.

Life cycle impact assessment

For the life cycle impact assessment, the ReCiPe Midpoint (H) V1.10/World Recipe H method was chosen (GOEDKOOP *et al.*, 2013). This methodology considers eighteen categories of impact: climate change (CC); depletion of the ozone layer (OD); terrestrial acidification (TA); freshwater eutrophication (FE); marine eutrophication (ME); human toxicity (HT); photochemical oxidant formation (POF); particulate matter formation (PMF); terrestrial ecotoxicity (TET); freshwater ecotoxicity (FET); marine ecotoxicity (MET); ionizing radiation (IR); arable land occupation (ALO); urban land occupation (ULO); natural area transformation (NLT); water depletion (WD); metal depletion (MD); and fossil depletion (FD).

In the study in question, characterization and normalization were possible using the SimaPro software, when applying the ReCiPe Midpoint (H) V1.10/World Recipe H method.

The characterization – the translation of the flow (input and output) into impacts – is the calculation of the results of the category indicators. To this end, factors were used that were estimated using mathematical models. For example, in the case of the category related to climate change, the characterization factor is the "CO_2-equivalent" measure, that is, CO_2, CH_4 and N_2O are converted to CO_2-equivalent. Thus, the results collected in the inventory are correlated to the environmental category to which they belong (ABNT, 2009b; GOEDKOOP *et al.*, 2013).

Standardization consists of calculating the magnitude of the indicators' results relative to baseline information (ABNT, 2009a). Thus, although not mandatory in LCA standards, the standardization procedure allows the identification of impact categories that are more relevant compared to the average impact (reference values) caused by other products, processes, and services. This standardization seeks to show to what extent an impact category has a significant contribution to global environmental issues (GOEDKOOP *et al.*, 2013).

RESULTS

The feed mill in which the data were collected belongs to a cooperative located in the city of Teresina, state of Piauí, Brazil. The members receive, in addition to feed for one-day aged chicks (the day after hatching, first day of life), specialized technical assistance. There are 32 direct jobs in the feed mill and some 1,600 direct and indirect jobs in the 64 integrated farms.

Monthly, the factory produces an average of 4,000 tons of feed, enough for a production of more than 2,000 tons of broiler. For this purpose, it consumes ingredients such as maize, soy, soybean meal, meat and bone meal, and other inputs, including sodium bicarbonate, sodium chloride, premix and so on.

The stages of feed production in the cooperative under study are described in the flow chart below (Figure 2).

Impacts of feed production per formulation

In the results of the environmental impact assessment for the production of 1 kg of broiler feed per formulation (pre-initial, initial growth, growth II, and final), differences in impact between formulations occurred mainly by the percentage of the macro-ingredients (corn, soybean and soybean meal) in each type of feed (Table 2). They are summarized in Table 3.

Impact contributors have been grouped into:

- ground corn;
- extruded soybeans;
- ground soybean meal;
- meat and bone meal;
- limestone;
- sodium chloride;
- electricity.

The comparative result of the characterization of the LCAs of the five formulations studied is represented in Figure 3.

When analyzing Figure 3, it is emphasized that there was an impact in all categories of the method being studied. Thus, it was possible to elaborate an impact ranking of the formulation of each category (Table 4).

Thus, it was possible to detect that the growth II feed had a greater impact in a greater number of categories (8 of 18), followed by the pre-initial feed (6 of 18).

After normalization, the categories that obtained the most prominence in the impact calculation, according to the reference values of the ReCiPe Midpoint (H) method, were: TET; NLT; FE; ME; and FET (Figure 4).

The impact in the NLT category had soybeans as its main contributor (pre-initial, 46.79%; initial, 81.70%; growth I, 81.25%; growth II, 84.49%; and final, 81.79 %), followed by maize (pre-initial, 43.98%; initial, 16.77%; growth I, 17.87%; growth II, 15.32%; and final 17.83%). This is due, among other things, to recent deforestation and the distance from the farms to the factory.

An important fact to consider is that, although the percentage of maize in the compositions exceeds 59%, the yield of maize per hectare is much higher than that of soybeans, reaching triple in the region of Uruçuí. This means that, to produce 1 kg of soy, more land is used than to produce 1 kg of maize.

Maize was the major contributor in 15 of the 18 categories analyzed (initial, growth I, growth II and final) and 16 of the 18 verified (pre-initial), with emphasis on FET (89-92%), FD (80- 84%), TET (79-93%), POF (76-88%), FE (74-91%), ME (67-76%) and MET (75-87%).

The impact in the CC category had soybeans as the main contributor (60-65%), followed by maize (33-58%) and soybean meal (0.64-19.93%). In the pre-initial formulation, its was the inverse: corn (58%), followed by soybean (22%) and soybean meal (19%).

Meat and bone meal, an ingredient of animal origin, determined negative values in all categories of the method analyzed, with emphasis on: FE (-13.11 to -19.04%), MET (-11.32 to -12.30%), OD (-8.21 to -11.13%) and POF (-6.96 to -7.61%).

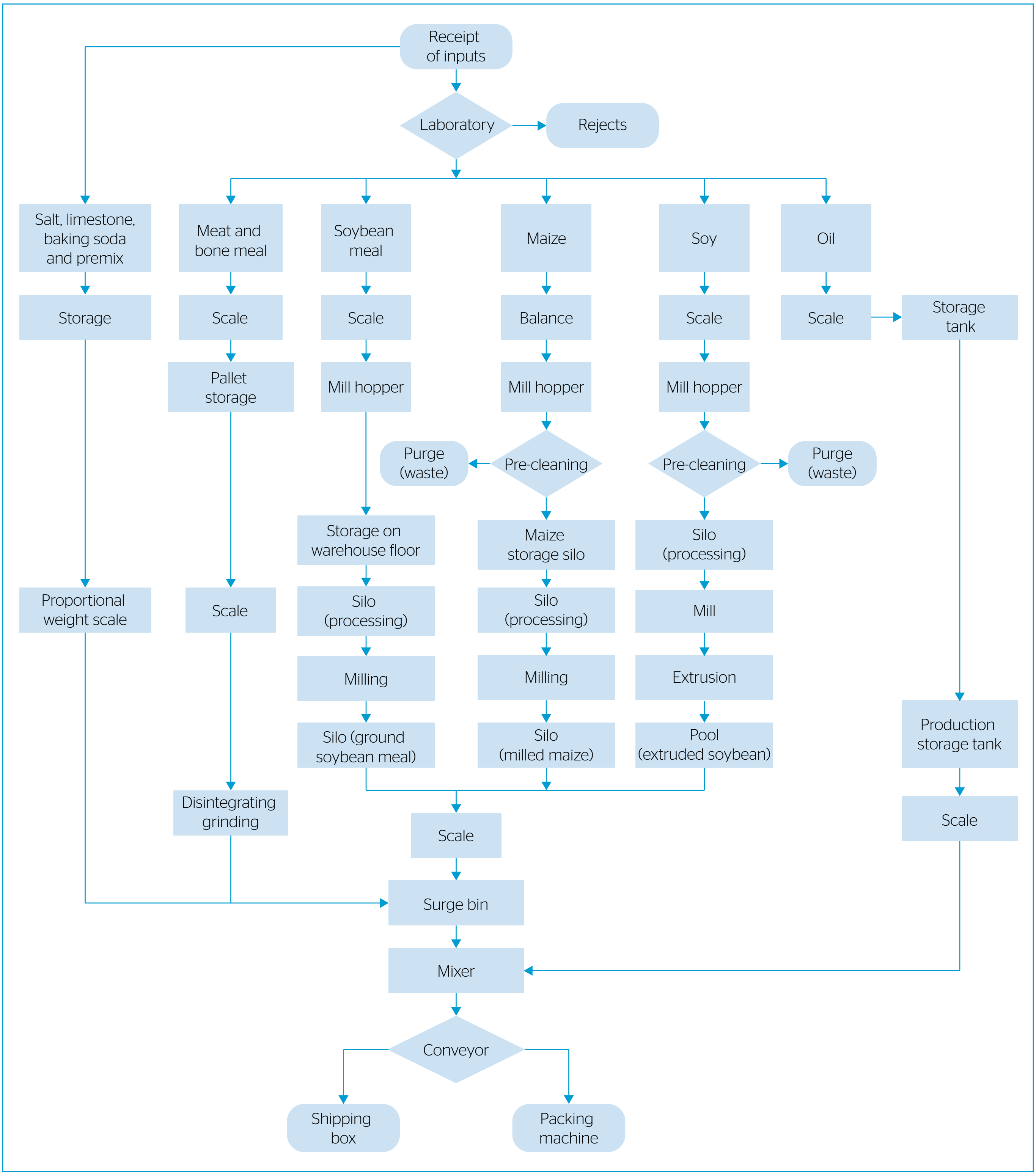

Figure 2 - Stages of feed production in the cooperative under study.

Table 3 – Analysis of contribution of potential impacts by feed formulation.

Impact category	Unit	Pre-initial	Initial	Growth I	Growth II	Final
CC	kg CO_2 eq	1.129	1.8382	1.8569	2.0524	1.9179
OD	kg CFC-11 eq	7.76E-09	6.26E-09	5.87E-09	5.38E-09	5.61E-09
TA	kg SO_2 eq	0.0128	0.0166	0.0174	0.0185	0.0182
FE	kg P eq	0.0003	0.0004	0.0004	0.0004	0.0004
ME	kg N eq	0.0094	0.0105	0.0107	0.0111	0.0110
HT	kg 1,4-DB eq	0.1023	0.1210	0.1257	0.1313	0.1301
POF	kg NMVOC	0.0027	0.0025	0.0025	0.0024	0.0025
PMF	kg PM10 eq	0.0023	0.0027	0.0028	0.0029	0.0029
TET	kg 1,4-DB eq	0.0129	0.0144	0.0153	0.0158	0.0159
FET	kg 1,4-DB eq	0.0061	0.0061	0.0065	0.0065	0.0067
MET	kg 1,4-DB eq	0.0012	0.0011	0.0011	0.0011	0.0011
IR	kBq U235 eq	0.0086	0.0082	0.0080	0.0078	0.0079
ALO	m^2a	2.5231	2.8764	2.9301	3.0301	2.9940
ULO	m^2a	0.0054	0.0051	0.0051	0.0049	0.0051
NLT	m^2	0.0078	0.0200	0.0203	0.0236	0.0212
WD	m^3	0.2512	0.3120	0.2905	0.3044	0.2832
MD	kg Fe eq	0.0062	0.0048	0.0044	0.0039	0.0041
FD	kg oil eq	0.1106	0.1126	0.1174	0.1183	0.1208

CC: climate change; OD: depletion of the ozone layer; TA: terrestrial acidification; FE: freshwater eutrophication; ME: marine eutrophication; HT: human toxicity; POF: photochemical oxidant formation; PMF: particulate matter formation; TET: terrestrial ecotoxicity; FET freshwater ecotoxicity; MET: marine ecotoxicity; IR: ionizing radiation; ALO: arable land occupation; ULO: urban land occupation; NLT: natural area transformation; WD: water depletion; MD: metal depletion; FD: fossil depletion.

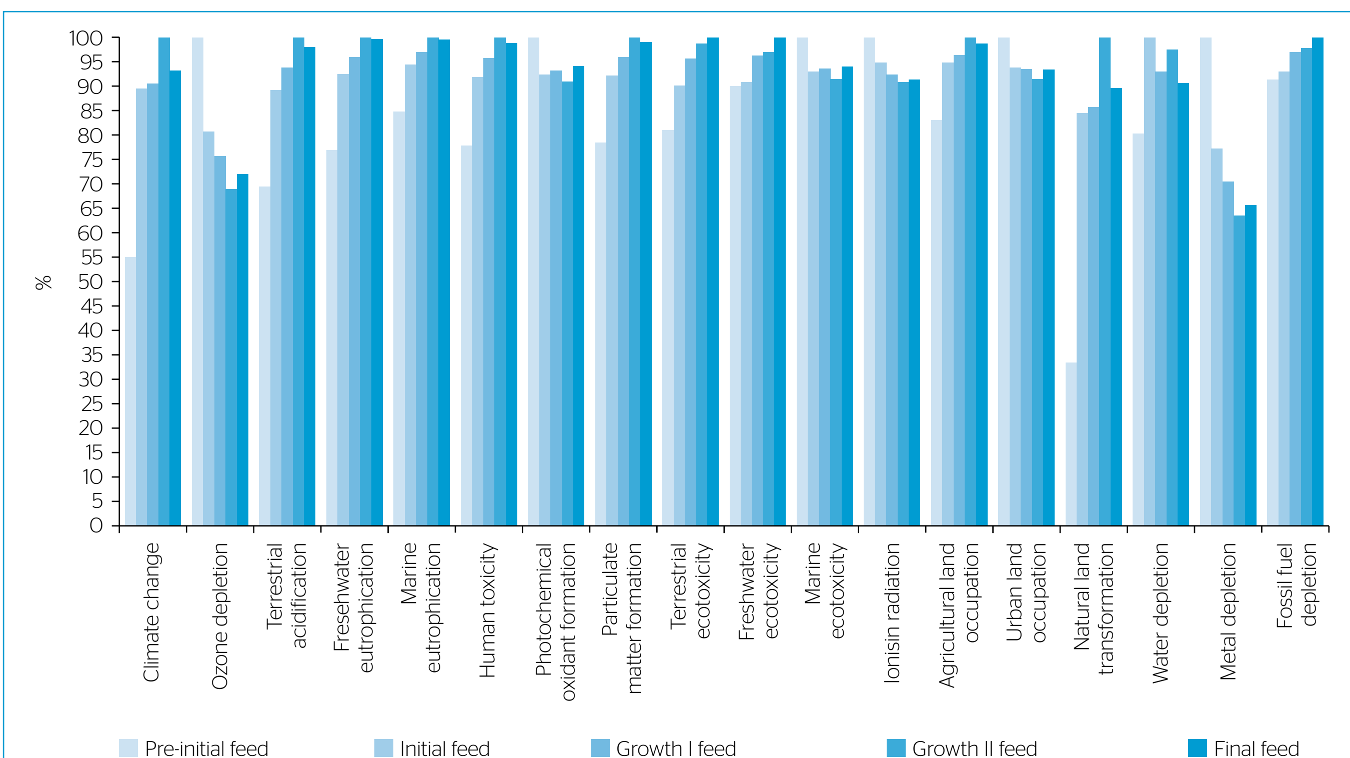

Figure 3 – Comparative characterization of potential impacts by formulation.

Table 4 – Ranking of Life Cycle Assessments (LCAs) of the formulations for each impact category analyzed.

Impact category	Order of magnitude of impact (1st, 2nd, 3rd, 4th or 5th)				
	Pre-initial feed	Initial feed	Growth I feed	Growth II feed	Final feed
CC	5th	4th	3rd	1st	2nd
OD	1st	2nd	3rd	5th	4th
TA	5th	4th	3rd	1st	2nd
FE	5th	4th	3rd	1st	2nd
ME	5th	4th	3rd	1st	2nd
HT	5th	4th	3rd	1st	2nd
POF	1st	4th	3rd	5th	2nd
PMF	5th	4th	3rd	1st	2nd
TET	5th	4th	3rd	2nd	1st
FET	5th	4th	3rd	2nd	1st
MET	1st	4th	3rd	5th	2nd
IR	1st	2nd	3rd	5th	4th
ALO	5th	4th	3rd	1st	2nd
ULO	1st	2nd	3rd	5th	4th
NLT	5th	4th	3rd	1st	2nd
WD	5th	1st	4th	2nd	3rd
MD	1st	2nd	3rd	5th	4th
FD	5th	4th	3rd	2nd	1st

CC: climate change; OD: depletion of the ozone layer; TA: terrestrial acidification; FE: freshwater eutrophication; ME: marine eutrophication; HT: human toxicity; POF: photochemical oxidant formation; PMF: particulate matter formation; TET: terrestrial ecotoxicity; FET freshwater ecotoxicity; MET: marine ecotoxicity; IR: ionizing radiation; ALO: arable land occupation; ULO: urban land occupation; NLT: natural area transformation; WD: water depletion; MD: metal depletion; FD: fossil depletion.

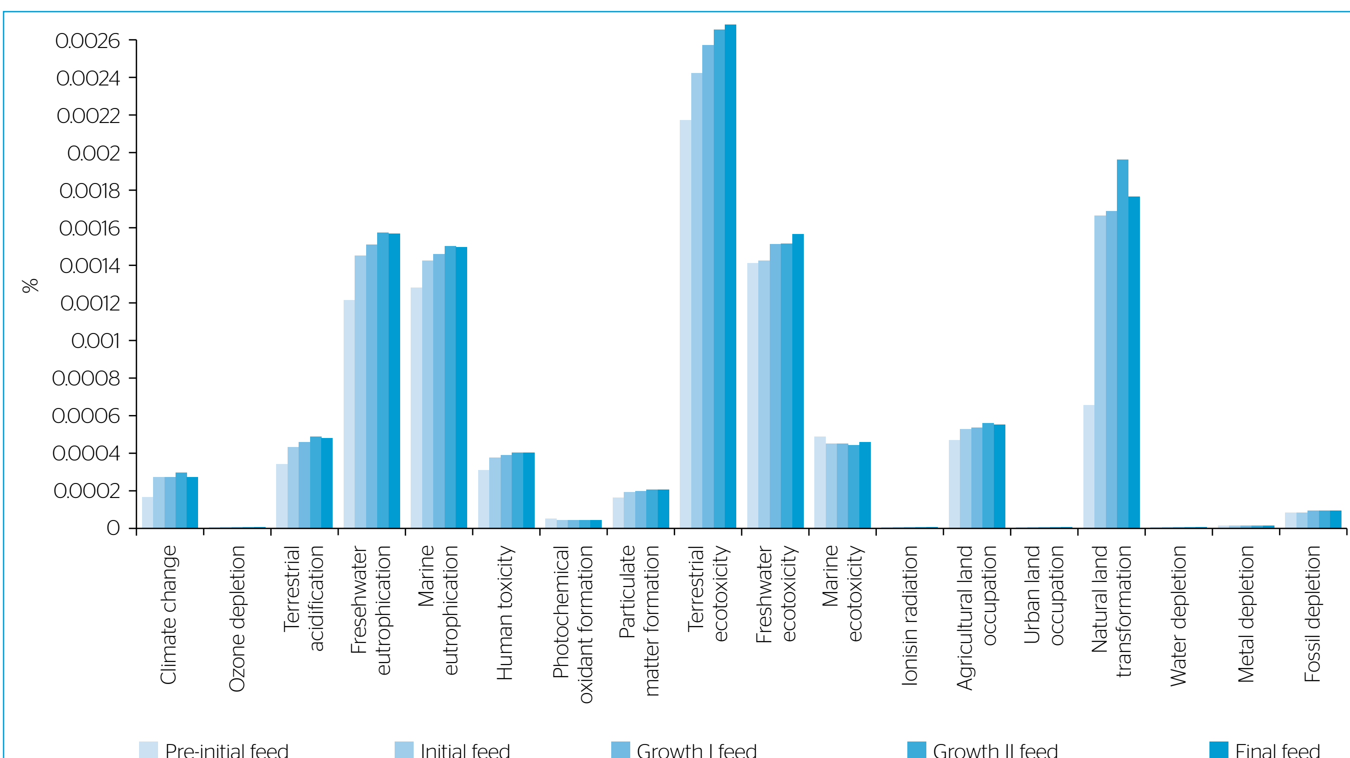

Figure 4 – Normalization of potential impacts by formulation.

DISCUSSION

Research that deals with environmental performance in the broiler sector shows that feed production dominates the contributions to the impact categories taken into account, especially in the production of high-energy and high-protein ingredients (PELLETIER, 2008; NGUYEN *et al.*, 2012; TONGPOOL *et al.*, 2012), which is confirmed in our study.

The energy and protein levels in the diet must respect the growing life stage of the growing birds: energy levels increase while protein levels decrease as the chicks age (Table 5) (ROSTAGNO *et al.*, 2011).

In this context, nutrition and food composition change according to age, requiring different formulations for each stage of the broiler's life.

Deforestation for the implementation of new grain plantation areas has a significant contribution to the environmental impact. According to Brasil (2014), the Piauí state's *Cerrado* has a high removal rate of its of native cover, as between 2002 and 2010 the southwest Piauí mesoregion was responsible for 10% of the deforestation in the country, with emphasis on the municipalities of Baixa Grande do Ribeiro and Uruçuí. By the year 2010, 16.6% of the state's *Cerrado* had been cleared, leaving more than 83% of the original coverage, which is equivalent to something around 77,585 km^2.

The region of Uruçuí, one of the main suppliers of maize and soybeans for the feed mill under study, stands out in terms of productivity. In recent years, the average yield of maize has increased to three times that of soybeans per hectare (Table 6 and Table 7).

In Piauí, the area planted with soybeans had accelerated growth, surpassing that of maize since 2010 (Figure 5). In 2014, maize occupied an area of 405,635 ha, while soybean occupied 626,799 ha (IBGE, 2016a).

In addition to deforestation, nitrogen and phosphorus emissions in agricultural activities and the use of pesticides to control pests and herbicides in weeds on maize and soybean farms are the main causes of environmental impact. One explanation for the impact on maize is due to the use of urea as a nitrogen fertilizer (SILVA *et al.*, 2014).

In the LCA studies, the negative impacts associated with transporting the beans to the gate of the factory where the feed is produced are also considered. In this sense, the greater the distance, the greater the impact. Initially, the impacts related to the construction of roads (JULLIEN; DAUVERGNE; CEREZO, 2014) and the manufacture of the means of transport (Bachmann *et al.*, 2015), as well as fuel consumption, must be taken into account. In a very simple way, the greater the distance, the greater the diesel consumption of the trucks that transport the grains and, therefore, the greater the amount of CO_2 in the atmosphere.

Meat and bone meal proved to be an ingredient that reduces the overall environmental impact on feed production. Tongpool *et al.* (2012),

Table 5 – Nutritional requirements of energy and protein for broiler.

Age, days	Pre-initial 1-7	Initial 8-21	Growth I 22-33	Growth II 34-42	Final 43-46
Metabolizable energy, kcal/kg	2,950	3,000	3,100	3,150	3,200
Protein % (males)	22.20	20.80	19.50	18.00	17.30
Protein % (females)	21.80	20.40	19.00	17.50	17.00

Source: Rostagno *et al.* (2011).

Table 6 – Average yield of maize production (kg.ha^{-1}).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Brazil	3,040	3,382	3,785	4,079	3,714	4,366	4,211	5,006	5,254	5,176
Piauí	661	873	585	1,135	1,546	1,193	1,936	2,860	1,783	2,749
Uruçuí	1,384	3,416	3,578	6,485	7,916	7,718	8,204	7,848	5,785	7,132

Source: IBGE (2016b).

Table 7 – Average yield of soybean production (kg.ha^{-1}).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Brazil	2,230	2,379	2,813	2,816	2,636	2,947	3,121	2,637	2,928	2,866
Piauí	2,818	2,345	2,234	3,230	2,821	2,531	2,982	2,793	1,727	2,375
Uruçuí	2,723	2,096	1,911	3,240	2,727	2,489	2,840	2,821	1,897	2,250

Source: IBGE (2016b).

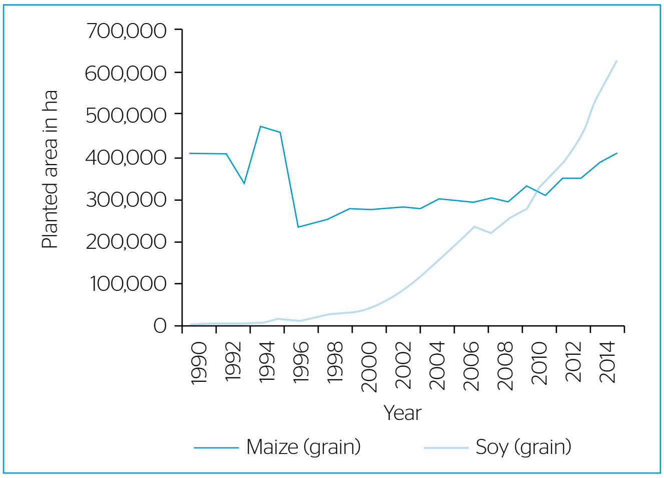

Figure 5 – Maize and soybean planted area in Piauí, in hectares.

in a study on the improvement of the environmental performance of broiler in Thailand, showed that the environmental impact of feed using animal ingredients is lower than the feed with ingredients of pure vegetable origin.

The productive process in the feed factory has electricity as its major contributor. Even so, its impact is relatively small. For example, in the CC category, it is somewhat less than 1%. Tongpool *et al.* (2012) point out that the environmental impact found in the production process in feed mills was relatively small.

CONCLUSIONS

The Piauí state's *Cerrado* is an expanding area of the agricultural frontier, therefore, an important site for grain production. Studies on the potential environmental impacts of agricultural production, especially those using LCA, can subsidize producers by identifying life cycle stages where the negative impacts are most significant and, therefore, identify points of intervention for environmentally sustainable actions.

With the use of LCA, it was possible to show that the greatest impacts of the production of rations for broiler occur on farms, especially in the production of maize and soybean. The main causes are the implantation of new crops through deforestation, the release of metals and nutrients from fertilizers, and the use of synthetic substances to control pests and weeds.

The negative environmental impact identified in the production process at the feed mill was relatively small. Knowing that the biggest impacts in the feed mill are related to the use of electricity, it is important that its consumption is minimized. In this sense, it is necessary to analyze the energy efficiency of all the equipment, as well as, when necessary, the exchange for high efficiency ones.

A positive environmental aspect found in this study was the use of meat and bone meal as an ingredient in feed formulations, as it is an alternative source of protein, calcium, and phosphorus, allowing the reuse of by-products from slaughterhouses (meat and bones), which could receive an environmentally inappropriate final destination.

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