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ECOLOGICAL FOOTPRINT OF DIFFERENT LAYING HEN PRODUCTION SYSTEMS IN SAN JERONIMO MUNICIPALITY ANTIOQUIA, COLOMBIA

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ABSTRACT

In recent years, fish production has increased worldwide due to population growth and consumer interest in this type of product, proving an increase in the waste generated, with concomitant negative impact on the environment. Ecological footprint methodology is one of the sustainability indicators most used for assessing process environmental impact. This technique quantifies the effect of anthropogenic activities on the environment concerning water, forest products, infrastructure and carbon footprint, providing integral, comparable and reliable results. In this study, the environmental impact generated by taking advantage of red tilapia (*Oreochromis Spp.*) viscera to produce chemical silage and its implementation in the feeding of laying hens was determined, using the ecological footprint methodology as an indicator of sustainability. The productive system consisted of a red tilapia (*Oreochromis ssp.*) production farm located in the municipality of San Jerónimo, Antioquia (Colombia). The productive variables of the laying hens, laying percentage, egg weight and feed conversion ratio were evaluated. This chemical silage production process generates a reduction of 1.493 kg of CO_2 per month compared to that generated by fresh viscera and are discharged into shallow dumps. Additionally, the main categories that generate the greatest impact on the production system are the use of natural resources and wastewater disposal. On the other hand, the productive variables of laying hens of the Isa Brown breed were not significantly affected by the inclusion of chemical silage at the 95% significance level, maintaining the percentage of laying and improving feed conversion. It was concluded that the use of fish by-products to produce feed for laying hens generates a reduction in the environmental load when compared to conventional waste disposal processes (landfill disposal). Red tilapia (*Oreochromis Spp.*) viscera chemical silage can be used as an alternative protein substitute in feeding laying hens for improved production performance.

Key words: Ecological footprint, fish waste, layer hen, chemical silage, wastewater

INTRODUCTION

Most of the agricultural activity developed by humans is connected to natural resources depletion, waste generation and green-house gases emissions [1]. Fish farming is among these activities with the highest growth in the last decades, in terms of productivity and economic importance, reaching 171 million tons worldwide in 2016. In Colombia, it was estimated that there was a 9% production growth for 2018, having red tilapia *(Oreochromis Spp.)* as the most important species, with 62% of production [2]. On the other hand, waste generated by this industry reaches 65% of the production, most of it disposed of inadequately, leading to environmental deterioration [3]. A significant amount of this waste has a rich composition in macronutrients, such as viscera, which can be used as a protein source to obtain raw material for the animal feeding industry [4].

Moreover, the high cost of poultry feeding is one of the main problems for this production chain, given that 95% of total dietary cost is used to cover energy and protein needs. The poultry industry has been the fastest-growing livestock sector in the last few years, driven mostly by a strong demand [5]. Fish and soy flour are the main protein sources, while corn flour is the main energy source [6]. However, these raw materials are in high demand, and they are not always available in countries like Colombia, making it necessary to import and increase the production costs of poultry feeding, something that encourages finding alternatives for such protein sources [6]. Among these alternatives, fish viscera silage comes out as a product with a significant lipid and protein content, stable for several months at room temperature, and with adequate nutritional characteristics for different animal species [4]. Despite chemical silage being a residue revaluation process, it uses chemical substances such as organic acids that may have significant environmental impacts, creating interest in the quantification of the environmental impact that its use on animal feeding may have.

Ecological footprint methodology is one of the sustainability indicators most used for assessing process of environmental impact [7]. This technique quantifies the effect of anthropogenic activities on the environment concerning water, forest products, infrastructure, and carbon footprint, providing integral, comparable, and reliable results [1]. The objective of this study was to determine the environmental impact of chemical silage obtained from red tilapia viscera *(Oreochromis Spp.)* and its implementation on laying hens feeding, by using ecological footprint a sustainability indicator.

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MATERIALS AND METHODS

Study location

The productive system consisted of a red tilapia (Oreochromis Spp.) production farm located in the municipality of San Jeronimo, Antioquia (Colombia) - 6°26'30"N 75°43'40"O with temperatures ranging between 18 and 25 ºC, an average relative humidity of 80% and rainfall between 1000 and 4000 mm/year, where it was proposed to process the viscera from tilapia fishing by chemical silage and use it later for laying hens *(Gallus gallus domesticus).*

Production system

Figure 1 represents the limits of the productive system, indicating product output and waste in each one of them.

Sub-system 1 (Subs1): Refers to the breeding and fattening stage of red tilapia (Oreochromis Spp.), where 2044 fingerlings were fed for 7 months until reaching an average weight of 400g. Fish were fed with 3 concentrated food diets according to each growth stage.

Sub-system 2 (Subs2): Consists of fish processing. One thousand seven hundred and seventy-eight (1778) fish weighing 400 grams were processed during this stage, corresponding on average to a mortality rate of 13%, where viscera waste represented 16% of total weight obtained.

Sub-system 3 (Subs3): Corresponds to the process of making chemical silage (CS), going through stages of degreasing, shredding, silage and storing, as reported by Suarez *et al.* [8]. One hundred percent (100%) of chemical silage obtained was directed to feeding laying hens.

Sub-system 4 (Subs4): Is the process of making diets for laying hens. Consists of three stages: mixing, pelletizing and drying. In Table 1, the defined formulation for poultry feeding is defined according to the nutritional requirements established on Brazilian nutrition tables [9].

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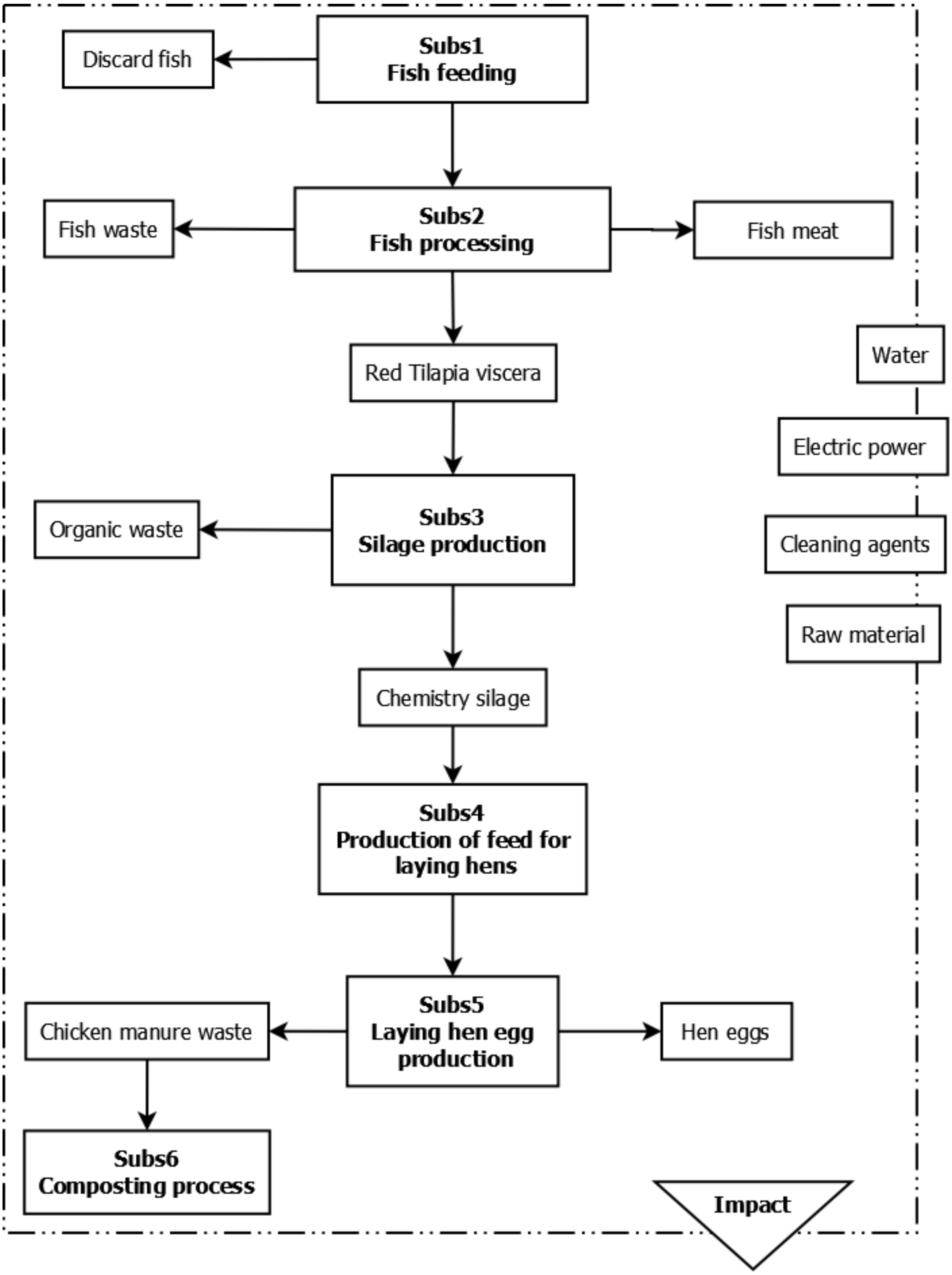

Figure 1: Limits of the production system

Animals and Management

Sub-system 5 (Subs5): Refers to the process to obtain chicken eggs; 36 Isa-Brown breed, 16-week-old, laying hens *(Gallus gallus domesticus)* were fed for a period of

7 weeks. The laying hens were randomly divided into two equal groups called the control group (commercial feed) and the silage group, which were subdivided into groups of 3 hens each. The hens were fed from week 16 to week 32. However, for the environmental impact analysis, a time estimate of one month was taken, while the productivity analysis was carried out for 7 weeks. The hens were fed twice a day (morning and afternoon) with a 107-gram ration per bird, providing a constant water supply.

Sub-system 6 (Subs6): Corresponds to the composting process of excretion waste obtained during poultry feeding stages.

Assumptions and limitations

For this study, some assumptions were considered, such as:

1) The Chemical Silage making process is carried out on the same farm where fish are bred, in order to eliminate viscera transportation effects.
2) Impact of buildings was not considered in calculations provided that their useful lifetime is long.
3) The environmental impact of industrial equipment was not included in the environmental analysis, as it has been proven that it does not significantly affect the evaluation results in the environmental impact because of its long period of useful life [10].
4) In the subsystem 4 (Subs4), it is considered that the only compounds released in the environment due to the drying process, are water steam molecules, this is attributed to the fact that the system does not attain temperatures conducive to the evaporation of other compounds at this stage.

Calculation of environmental impact

For the environmental impact analysis of the production system observed on Figure 1, the ecological footprint study was used. This methodology was carried out by using calculation models that estimate the ecological impact of each stage of the system [7]. Since it uses a significant amount of information, results are more precise and, at the same time, reduce limitations when international databases that do not have all the information are used without adjustment to the region where they are applied [11]. For ecological print calculation, breeding 2044 red tilapia fish (*Oreochromis Spp.*) was considered as the fundamental unit. The environmental impact of input and output values from every stage of the production system were normalized to the same unit (Ha/ton), which indicates the number of forest hectares needed in a specific region to capture the CO_2 produced during each stage of the system [7].

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Equation 1 was used for calculating environmental impact (IAco) caused by organic compounds (co) used or created in each stage of the production system. It was carried out as established by the Intergovernmental Panel on Climate Change (IPCC) Guidelines, where CRO corresponds to the amount of organic waste; FCM, to the correction factor for methane gas (CH_4) which depends on the process associated to solid waste management in a particular sector [12]. The degradable organic carbon fraction of the waste that can be subject of biochemical decomposition is represented by COD (degradable organic carbon) [12], CODF (degradable organic carbon fraction) is the non-assimilated or very slowly degrading COD fraction [12], F and R correspond to the CH_4 fraction in the landfill gas and the CH_4 recovered fraction, respectively. The methane (CH_4) oxidation factor is represented as OX, methane global heating potential (PCG) was used for a 100-year period [12], and FF corresponds to the CO_2 capture factor for the region established in the environmental analysis [13].

$$IA=\sum_{co=1}^{n} CRO\left(\frac{16^{*}(FCM^{*}COD^{*}COD_{F}^{*}(F-R)^{*}(1-OX)^{*}PCG)}{12^{*}FF}\right) \quad (1)$$

The environmental impact coming from the electric energy input during the different stages was calculated using Equation 2, where EEG corresponds the electric energy expense in each stage (e) of the process, and EEE is the CO_2 emission factor caused by a kw-h energy [13].

$$IA=\sum_{e=1}^{n} EE_{G}{}^{*}\frac{EEE}{FF} \quad (2)$$

In sub-system 3, during chemical silage making stage, a degreasing process takes place by propane gas heating. In order to determine its impact, the calculation is performed using Equation 3, where VRC_3H_8 is the gas volume required for the process; EBp is the energy imbued in the process of obtaining propane gas; the distance covered in transportation, fuel mileage and propane gas loads are marked with DR, Rc and C, respectively. Finally, CO_2 emissions coming from fuel were marked as EC. Additionally, there is generation of CO_2 in that sub-system because of propane gas combustion process, for which its impact was calculated by Equation 4, where FCC_3H_8 corresponds to the conversion factor for propane gas, and FEC_3H_8 is the CO_2 emission factor [12].

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$$IA=VR_{C_3H_8}\left(\frac{EB_P*EEE+\left(\frac{D_R}{R_C*C}\right)*EC}{FF}\right) \quad (3)$$

$$IA=\frac{VR_{C_3H_8}*FC_{C_3H_8}*FE_{C_3H_8}}{FF} \quad (4)$$

Including an input flow corresponding to cleaning water for equipment and spaces for processing is necessary in the different sub-systems. For this, the impact caused by water flow was calculated with Equation 5, where AL corresponds to the liters of water required in the process (a); and EBA is the energy imbued for water supply. However, using this brings an environmental impact associated to its final arrangement, which is calculated using Equation 6, where ARL corresponds to wastewater obtained in the cleaning process; $CODBO_5$ is the biochemical oxygen demand from the degradable fraction of waste water; and $CMPCH_4$ indicates the maximum amount of methane production that such fraction has [12].

$$IA=\sum_{a=1}^{n}A_L\left(\frac{EB_A*EEE}{FF}\right) \quad (5)$$

$$IA=\sum_{a=1}^{n}AR_L*\left(\frac{CO_{DBO5}*CMP_{CH_4}*FCM_{CH_4}*PCG}{FF}\right) \quad (6)$$

For the environmental impacts associated to production ingredients and other input flows in the different sub-systems, Equation 7 is used, where CRI is the "i" product quantity required; EBPI corresponds to the energy imbued for its manufacture; and CI the maximum load in product transportation [12].

$$IA=CR_I\left(\frac{EB_{PI}*EEE+\left(\frac{D_R}{R_C*C_I}\right)*EC}{FF}\right) \quad (7)$$

Productive Variables

Egg laying percentage was assessed by dividing the number of eggs laid every day by the total of hens. Eggs were collected, counted and weighed daily on a 1g precision analytical scale (TxB220-1L from Shimadzu, Japan) for 7 weeks to determine laying percentage and their average weight. Feed conversion ratio

(FCR) was assessed weekly by taking food consumption in kilograms and dividing it into the number of egg dozens [14].

Statistical analysis
The data collected were evaluated at a confidence level of 95% by means of the hypothesis test to determine the difference in means using Fisher's LSD (Least significant difference) test with statgraphics centurion XVI software.

RESULTS AND DISCUSSION

Productive Variables

Productive parameters of laying hens fed with a partial protein substitution by chemical silage of red tilapia viscera are shown on Table 2. Concerning egg laying percentage, it is observed that the values are between 82 (week 0-1) and 100% (week 5-6), these values are typical of this line of laying hens [15], thus indicating that degreased chemical silage in laying hens did not have negative effects on laying percentage, pointing out that nutritional features of diets were adjusted to requirements. Similar results were reported by Kjos *et al.* [16]. However, 5% silage was used in that study. Also, Silva [17], found that laying percentage in hens increases when including fish by-products due to protein availability and the lipid profile which is an important source of energy needed for egg production [17].

Egg weight showed an increase during the weeks of the study, as reported by Padhi [18], who concluded that hen eggs increase weight until the age of 52 weeks in the birds. Similar weights were reported by Batalha [18], using a water substitution in the original formulation up to a maximum of 3% of silage, which may indicate that higher silage concentration does not affect egg weight significantly in time. On the contrary, such substitution could actually favor it, especially due to the quality of dietary lipids, given that vitellogenesis and laying depend highly on lipid and energy levels in the ovary [17,19]. Feed conversion ratio was in a range between 1.28 and 1.56 kg feed per egg dozen. These values show a better feed conversion compared to the results shown by Batalha [18], who had conversions between 2.01 and 1.56 kg per egg dozen, indicating that chemical silage inclusion favors feed conversion in terms of egg unit.

Quantification of environmental impact of chemical silage use in bird feeding
Results obtained with the use of silage in feeding laying hens justify the quantification of the environmental impact this process causes. For that, quantification of environmental impact, and product quantity or waste obtained in each sub-system of the process (Fig. 1) are shown in Table 3. In fish breeding

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(subs 1), mortality caused an average reduction of 13% in the initial population (2044 fish), being a typical range of a productive cycle of this nature, which is usually 10 to 20 % [20]. That sub-system shows the highest environmental impact in the whole production system (0.574 ha/month), given that the significant quantity of feed consumed by fish during their breeding, and the growth of certain raw materials used to fulfill this requirement, are associated to high emission of greenhouse gases [21].

On fish growth stage (Subs 2), scales (5%) and viscera (16%) are removed, giving an average weight yield of 79%. This stage shows a considerably higher environmental impact when compared with further stages, due to the high volume of water required during evisceration, resulting in waste water with a high organic load, which in most cases is spilled into the environment [22].

Subs 3 corresponds to the process of obtaining chemical silage, it shows a 71% yield after degreasing stage, thus obtaining 80.73 kg of CS a month. This product is then used in laying hens' feed manufacture process as a protein substitute of conventional raw material (soybean and fish flour). Environmental impact on this stage shows a value of -0.144 ha/month. It is expressed in negative because, if there were not any exploitation of the by-product (viscera), there would be an adverse environmental impact equivalent to that magnitude. Similar behaviors were reported by Malakahmad [23], where environmental impact of different organic waste disposal processes was determined, reporting that CO_2 emissions avoided in anaerobic digestion process are considerably higher than total CO_2 emissions of the process, giving a negative value as a result, meaning that the process is favorable for the environment [23].

Sub-system 4 is the feed making process for laying hens, it has relatively lower environmental impacts when compared to other stages of the production systems, and its main impact categories focus on obtaining raw materials and electric energy use in concentrated feed pelletizing. Drying process was carried out by using solar collectors, as reported by Camaño [24], intending to reduce environmental load from feed making process. By doing this, the production system goes into the tendency of using renewable energies in food drying processes, since the environmental performance assessment of several poultry farms and processing plants has shown that one of the main environmental pressures in poultry farms is feed production because of its high energy and heat consumption, and the use of raw materials such as soybean, which require application of mineral fertilizers [24].

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Feed conversion ratio (FCR), has relevance in egg production from the environmental point of view, given that poultry generates a significant amount of greenhouse gases during their digestive process, such as methane. This variable relates the amount of gas produced per feed unit consumed for a meat or egg unit produced [25]. Sub-system 5 shows the values of environmental impact on laying hens feeding, which is mainly affected by feed consumption, as it is directly related with the amount of manure produced and its composition, influencing on the emissions from the poultry industry productive system (growth and product generation). Similar behaviors were reported by Leinonen [26], who concluded that changes in food consumption and composition have effects both on environmental impacts during growth production and food processing, as well as on subsequent emissions from poultry manure during housing, storage and field application.

The different physical and chemical features of poultry excretions provide them with qualities to be used either as fertilizer or animal feed [26]. However, when they are not exploited properly, they emit gases such as ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) at a lower proportion, which are produced during the productive, storage and land application stages [27]. In sub-system 6, manure generated showed a negative value, meaning that it was an environmental credit rather than a load. This is because manure was used as a fertilizer, which compensated for the production of synthetic fertilizers or nitrogen-sequestrating rotational crops.

The main categories of impacts on sub-system inputs and outputs can be observed on Figure 2. Greenhouse gases emission sources in monthly kg CO_2 are notorious. Using alternative energies such as solar drying in feed making process for poultry species caused a significant reduction of CO_2 emissions in that category, because solar energy used is a free, renewable, abundant source, which makes it one of the most promising alternatives to reduce the environmental impact on drying processes, given that using electric energy is usually known as one of the highest impact indicators concerning environmental quantification [28]. Concerning wastewater disposal, it is the category with the highest environmental impact when observed, mostly due to the organic load that it has, which makes it difficult to be disposed because it requires large amounts of oxygen for its degradation, reducing its capacity to assimilate contaminating load and naturally restore its quality [22]. Using natural resources for raw material growth and supplies needed for making both fish and poultry feeding represents the second source of environmental impact of the production system. Similar results were reported by Leinonen [29], which showed the relatively high impact of concentrated feed production in poultry industry (over 70% of the total global warming potential).

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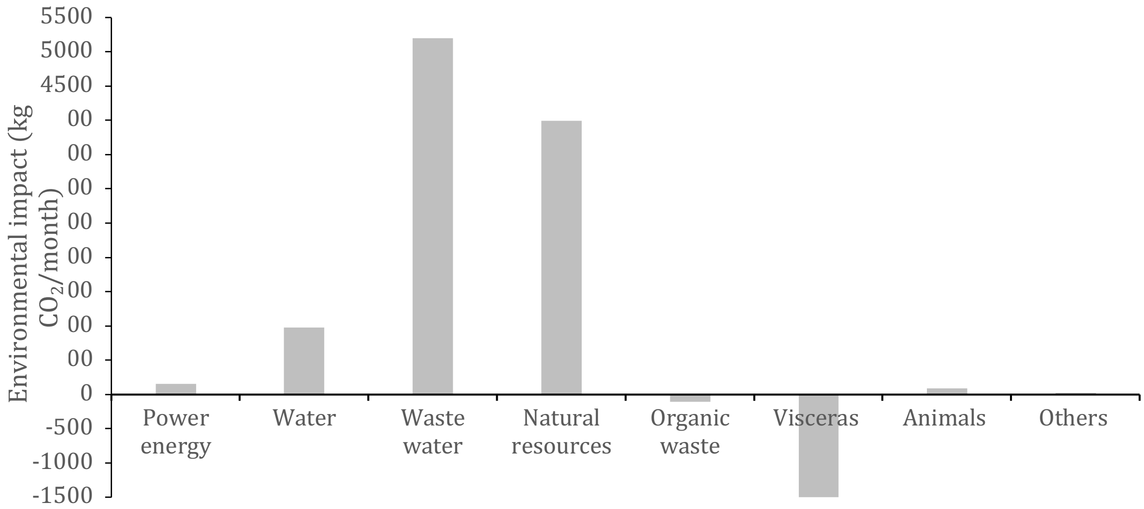

Figure 2: Environmental impact categories

Exploitation of organic waste from both fish (viscera) and poultry (excretions) industries favor a reduction of environmental impact directly. In addition, it generates an added value to the by-products that affects the economy of the process. Exploitation of by-products from fish and poultry industries brings a reduction of environmental impact. However, it is inevitable that in the processing of such residuals, new environmental impact sources may evolve. Therefore, it is not possible to eliminate it completely [30].

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

Red tilapia *(Oreochromis Spp.)* viscera chemical silage can be used as alternative protein substitute in laying hens feed manufacture without modifying production parameters and improving feed conversion. Exploiting fish by-products for laying hens feed manufacture reduces environmental load when compared with conventional waste disposal processes (landfill disposal) indicating that it is the most environmentally favorable production system. On the other hand, natural resources use, and wastewater disposal are the main sources of adverse effects on the environment in this process. However, implementing renewable, efficient, alternative energies, reduce the environmental load of the process, in addition to making products with a commercial value.

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Table 1: Formulation of layer hen diets (%)

RAW MATERIAL	Percentage
Soybean meal	8.10
Fish meal	6.85
Chemical silage	21.91
Corn meal	35.34
Rice flour	13.06
Fish oil	1.00
Calcium carbonate	8.09
Dicalcium phosphate	4.04
Vit. min. Supplement*	0.40
Methionine	0.30
Lysine	0.30
Tryptophan	0.30
Threonine	0.30

*composición por 250 g de producto: vit. A - 1.400.000 IU; vit. B1 - 500 mg; vit. B12 - 300 mg; vit. B2 = 500 mg; vit. B6 – 1.6 g; vit. D3 - 2.500.000 IU; vit. E - 6.000 IU; vit. K3 = 1.000 mg; biotina - 30 mg; niacina -12 g; ácido fólico - 1 g; cobalto - 50 mg; cobre - 3.000 mg; hierro - 25 g; yodo - 500 mg; manganeso - 32.5 g; selenio - 100.50 mg; zinc - 22.49 g.

Table 2: Productive parameters of laying hens

WEEKS	Laying percentage (Control)	Laying percentage (Silage)	Egg weight (g) (Control)	Egg weight (g) (Silage)	FCR (kg feed/dozen eggs) (Contro)	FCR (kg feed/dozen eggs) (Silage)
0-1	85.71 ± 3.52	82.14 ± 4.30	49.80 ± 1.47	49.67 ± 3.51	2.28 ± 1.30	1.56 ± 1.06
1-2	84.72 ± 4-.54	85.71 ± 5.81	55.23 ± 2.49	51.72 ± 2.24	2.04 ± 1.34	1.50 ± 2.30
2-3	85.22 ± 2.13	82.14 ± 4.53	58.14 ± 2.48	51.79 ± 3.68	1.93 ± 1.54	1.56 ± 1.35
3-4	80.29 ± 1.92	85.71 ± 2.76	58.28 ± 1.56	52.34 ± 5.14	2.08 ± 1.42	1.50 ± 1.94
4-5	85.71 ± 5.42	85.71 ± 4.69	57.90 ± 1.45	56.51 ± 2.61	2.05 ± 1.29	1.50 ± 2.26
5-6	86.20 ± 3.17	100.00 ± 3.26	60.14 ± 2.61	69.52 ± 1.74	2.02 ± 1.67	1.28 ± 2.08
6-7	86.22 ± 3.68	89.29 ± 3.18	58.85 ± 3.64	72.40 ± 3.15	1.56 ± 1.22	1.44 ± 1.38

FCR: Feed conversion ratio

Table 3: Environmental impact of the production system

SUBSISTEM	Quantity	Environmental Impact (Ha/month)
Subs 1	1778.28	0.574
Subs 2	561.94	0.468
Subs 3	80.73	-0.144
Subs 4	159.79	0.083
Subs 5	1350.00	0.179
Subs 7	200.00	-0.108
Total		1.054

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