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Benchmarking the environmental performance of best management practice and genetic improvements in Egyptian aquaculture using life cycle assessment

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ABSTRACT

Egyptian aquaculture is gaining importance as an affordable and nutritious source of animal protein among Egyptians. Nile tilapia dominates production (77% of total production), followed by carps (17%) and mullets (11%). Egyptian tilapia farmers are, however, facing challenges with regards to financial viability and poor water quality. Fish farms are also contributing towards water pollution and other environmental impacts. In order to improve the situation, WorldFish launched the IEIDEAS project in 2011 with the ambition to train farmers in best management practices (BMP) and distribute the 9th generation of the Abbassa strain (G9). The present study aimed at evaluating any relative environmental gains that BMP and G9 offers compared to conventional farming using life cycle assessment (LCA). Inventory data representing 137 farmers and four groups (control, BMP, G9 and BMP + G9) were evaluated. Life cycle impact assessment results including quantitative uncertainties were then calculated and statistically tested, using Monte Carlo analysis and Wilcoxon paired significance test. Five impact categories were explored: global warming, eutrophication, acidification, freshwater consumption and land use. The G9 stain offered the greatest improvements across the evaluated impact categories, significantly reducing environmental impacts with between 12% and 36%. BMP, in the meantime, only offered significant improvements compared to the control with regards to eutrophication, acidification, freshwater consumption and land use. Meanwhile, BMP + G9 performed comparably to only G9 except for eutrophication where it had a significantly larger environmental footprint. More efficient feed utilization and higher productivity were the main reasons for the environmental improvements. Additional improvements that should be explored include improved feeds made of sustainably sourced raw materials, and better pond water management, including probiotics and paddle-wheels.

Statement of relevance: BMP and improved stains help reduce environmental impacts

1. Introduction

Egypt has been granted great agricultural wealth by the Nile River. Over the millennia that the Nile River delta has been cultivated, several irrigation projects have been carried out, expanding the area of cultivable land. Alongside the expansion of agriculture, aquaculture has been encouraged as a source for animal-protein (Khalil and Hussein, 1997). The fish species dominating these aquaculture systems is also the most commonly farmed fish worldwide, a fish that owns its name to the great river, namely the Nile tilapia (*Oreochromis niloticus*).

Farming of tilapia and other fish in Egypt has increased over twenty-fold over the last two decades and now provides around 77% of the fish produced in the country, thus becoming the third largest animal production sector in Egypt (Fig. 1) (El-Sayed et al., 2015; FAO, 2016). Of the 1,113,000 tonnes of fish produced in 2014, 67% were Nile tilapia, 17% cyprinids (mainly common carp, *Cyprinus carpio*), 11% flathead grey (*Mugil cephalus*) and thin-lipped mullets (*Liza ramada*), and marginal production (between 0,6% and 2%) of African catfish (*Clarias* spp.), sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*) and shrimp (*Penaeus* spp.) (FAO, 2016). Most of these fish were produced in ponds located in the northern regions of the country. The farming season for tilapia in ponds stretches from eight to nine months, from March/April to November/December (Macfadyen et al., 2012), with most farmers only yielding one crop per year. Feed is the largest operating cost, making up 75–90% of the production cost (El-Sayed et al., 2015), followed by fish fry, land rent, electricity and diesel (Macfadyen et al., 2011).

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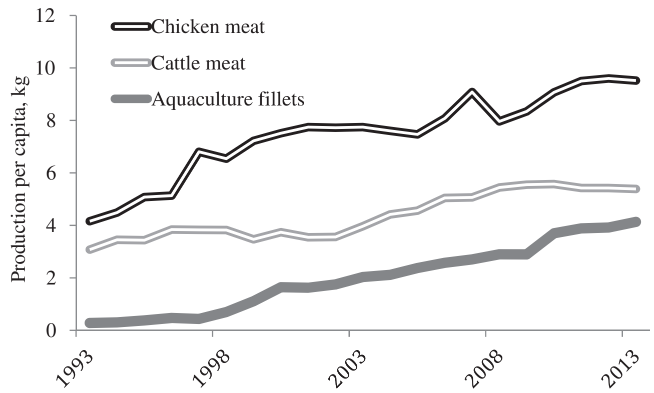

Fig. 1. Animal food products per capita in Egypt from 1993 to 2013. Data: FAO (2015) and FAO (2016).

Most farmed fish are consumed locally in Egypt, offering a relatively cheap source of animal protein, with market prices even declining over the past decade (Macfadyen et al., 2011). Feed producers, in the meantime, import between 50 and 99% of their raw materials (El-Sayed et al., 2015). Some agricultural ingredients are domestically available (e.g. wheat bran and rice bran), while soybean, fishmeal and fish oil are almost exclusively imported. The inclusion of meat and bone meals (MBMs) in aquaculture feeds is not officially allowed, but still occurs at low quantities in some feeds (El-Sayed et al., 2015). Rising global raw material prices and limited market prices for fish have, however, decreased the profit margins for Egyptian aquaculture farmers over the last few years (Dickson et al., 2016).

Apart from monetary challenges, Egyptian fish farmers are also faced with fresh water limitations, both qualitative and quantitative. Growing populations and more extensive freshwater use have increased the competition for Nile river water, resulting in a prohibition on the use of irrigation water in aquaculture (Khalil and Hussein, 1997). With the exception of some government owned farms, hatcheries and experimental facilities that have been granted direct access to irrigation water, most fish ponds, by law, have to use agricultural drainage water as their primary freshwater source (Eltholth et al., 2015). This drainage water is generally of low quality and its salinity can range from 0 to 3 ppt due to accumulation of minerals. In the northern parts of the country, the problem is even more acute, as marine water can enter directly into aquaculture ponds during low-water events (Eltholth et al., 2015). Fish farmers have responded to this problem by increasing the exchange of water, but this has had limited success as the replacing water is generally of equally poor quality.

In an attempt to improve the financial situation for Egyptian aquaculture farmers, increase employment and reduce environmental impacts, WorldFish launched the IEIDEAS[1] project in late 2011. This three-year project, supported by the Swiss Agency for Development and Cooperation and implemented in partnership with CARE and the Egyptian Ministry of Agriculture and Land Reclamation focused on BMP training of fish farmers (Dickson et al., 2016), as well as dissemination of the Abbassa improved strain of Nile tilapia to Egyptian fish farmers. During the project, BMP training was delivered in short, field-based training sessions by farmer-trainers to over 2500 fish farmers and technicians, while generation nine of the Abbassa improved strain of Nile tilapia (G9) was distributed to over 500 fish farms.

In the present study, we aim to benchmark potential environmental gains offered by BMP and the improved Abbassa G9 tilapia strain, compared to conventional tilapia farming in ponds, using LCA. LCA is an environmental accounting tool that evaluates the impacts resulting throughout a product's lifecycle (generally from the extraction of raw materials to the farm-gate, retail or landfill in aquaculture LCAs), and scale these to a functional unit (unit of reference). The framework is supported by its own ISO standard (ISO 14040–14044, 2006) alongside numerous other guidelines. To date, in excess of 50 LCA studies have been carried out on seafood, many focusing on aquaculture (Avadí and Fréon, 2013; Ziegler et al., 2016). However, only one of these has evaluated aquaculture in Egypt, a comparative study between semi-intensive and intensive tilapia farming by Yacout et al. (2016). The conclusions by Yacout and her colleagues were that intensive farming performed worse with regards to GW[2], ACD[3] and EU[4], but not with regards to EUT.[5]

In addition to the impact categories explored by Yacout et al. (2016), apart from energy use, the present study will also evaluate freshwater FWC[6] and LU.[7] Variance in data were also quantified and propagated using Monte Carlo sampling, yielding ranges rather than point-values (Henriksson et al., 2014). This together with the use of conventional farming as a control group and dependent sampling allowed us to reach statistically supported conclusions (Henriksson et al., 2015a).

The structure of this manuscript initially follows ISO's four phased LCA structure of: *goal and scope*, where the aim of the study, the intended audience, data sourcing, methodological choices and other choices of importance for interpreting results are described; *life cycle inventory*, where the sourcing of data is detailed; *life cycle impact assessment*, where the economic and environmental flows in the life cycle inventory are classified and characterized into impact categories (e.g. CO_2 and CH_4 to global warming); and lastly *interpretation*, where the results are analyzed and conclusions drawn. The material and methods section will initially detail choices related to these four phases in Section 2, followed by the life cycle inventory and life cycle impact assessment results discussed in Section 3. Contribution analyses are available in the supplementary material of this article, but with environmental hot-spots highlighted in the results section. Possibilities, challenges and limitations of this study are then discussed in Section 4. Finally, the major outcomes and implications for the Egyptian aquaculture industry are reflected upon in Section 5, conclusions.

2. Material and methods

2.1. Goal and scope

This LCA study was carried out to evaluate the advancements of the IEIDEAS project, financed by the Swiss Agency for Development and Cooperation (SDC) and implemented by WorldFish. The goal of the study was to benchmark the environmental benefits of the Abbassa G9 tilapia strain and BMP using LCA. The outcomes are aimed at policy makers and NGOs in Egypt and elsewhere that work with improving aquaculture production practices.

Four farming practices were evaluated: conventional farming, BMP farming, farming using the G9 strain, and BMP farming using the G9 strain. The functional unit, the unit of reference in the comparisons, was one tonne of live tilapia at farm-gate. The system boundary included electricity generation, fuel refining, agriculture, capture fisheries, fishmeal production, poultry farming, hatchery, feed processing, aquaculture grow-out among other processes (Fig. 2). Allocation of environmental impacts among several products originating from the same unit process (e.g. fishmeal and fish oil) was solved using first mass and later economic value (monetary value times mass) consistently throughout the primary dataset (pre-allocated processes in ecoinvent v2.2 were not altered). These allocation methods were chosen as they both could be consistently applied to all allocation scenarios encountered and

[1] Improving Employment and Incomes through the Development of Egypt's Aquaculture Sector.

[2] Global warming.
[3] Acidification.
[4] Energy use.
[5] Eutrophication.
[6] Freshwater consumption.
[7] Land use.