# Are the Post-harvest Losses of Nile-perch Value Chain in Lake Victoria in Tanzania a Driver of using Pesticides for Fish Storage?

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**Abstract**

*Post-harvest losses are major causes of economic and nutritional losses in the Nile perch value chain. Literatures indicate that the value of the total post- harvest losses on the Nile perch value chain as a percentage of the expected value of all the fish landed is 31%; whereby the quality loss constitutes 12.1% while physical loss accounts for 18.9%. This huge loss has necessitated fisher folks to use different alternatives that are possible to fight such post- harvest losses. This study was conducted in Lake Victoria to assess whether post-harvest losses on the Nile perch value chain are important drivers of using chemical pesticides in fish storage. The study involved fresh fish samples collection from the designated landing sites and processed products (salted- sundried, smoked, deep-fried and trims) from the markets. Samples extraction and cleanup was carried out using a QuEChERS method and analysis using a Gas Chromatography equipped with electron capture detectors (GC- ECDs). The results indicated high levels of organochlorine pesticides in processed Nile perch products than in the fresh fish muscles. The concentrations of organochlorine pesticides (OCPs) in fresh fish muscles ranged from below the limits of detection (<LOD) to 0.4 µg/kg whereas in processed fish products the OCPs concentration ranged from <LOD to 2.20 µg/kg. In this study, only four OCPs (β-HCH, HCB, Dieldrin and Aldrin) were detected in fresh fish muscles while nine OCPs (α- HCH, β- HCH, Lindane, HCB, Dieldrin, Aldrin, p, p- DDE, α- endosulfan, Oxychlordane and α- chlordane) were detected in processed fish products. This suggests use of chemical pesticides in the fish value chain for preventing post-harvest losses and that post-harvest losses could be significant contributors towards use of pesticides during fish processing and storage.*

***Keywords:*** Post-harvest losses, Nile perch, Lake Victoria, Organochlorine pesticides

## Background information

Post-harvest losses are major causes of economic and nutritional losses in the fish value chain. Literatures indicate that the value of the total post- harvest losses on the Nile perch value chain as a percentage of the expected value of all the fish landed is 31%; whereby the quality loss accounts for 12.1% while physical loss constitute 18.9%. This study is in line with Sustainable Development Goals (SDGs) especially Sustainable Development Goal (SDG) 12 which states that 'Ensure sustainable consumption and production patterns'. More specifically, this SDG aims that "by 2030, to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" in the fish value chain (ACP, 2019). This is aimed at reducing 50% of the post- harvest losses and waste along the whole food chain for sustainable production and consumption.

It is further estimated that food loss and waste for the global fisheries sector amounted to 35% of total catches. Similarly, the study indicated that catches ranging between 9 and 15% of these losses were due to fish discards at sea and the losses found along the whole fish value chain, from production to the consumer (FAO, 2010; FAO, 2011; FAO, 2020). It is also indicated that in the Sub-Saharan Africa countries, 15% of total losses 35% occur at fishing stage (e.g. discards), 16% during post-harvest operations (e.g. landing, storage, transportation), 24% during processing operations, 40% during distribution (deterioration occurring in the market system) and 5% at consumption stage at household level (Fig. 1). The huge losses that occur during the fish value chain trigger fisher folks to devise different mechanisms for minimization of the losses.

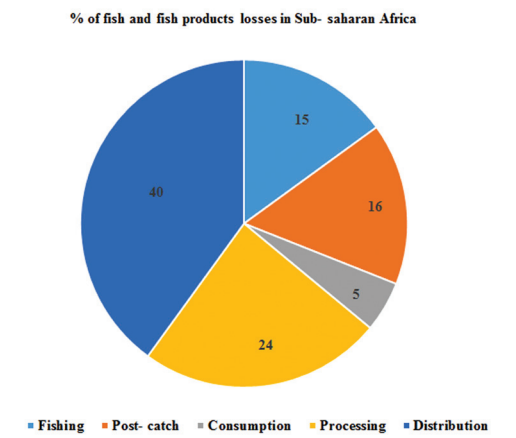


**Figure 1: Fish and fish products losses in Sub-Saharan Africa (*Source:* FAO, 2011)**

Many countries including less developed countries like Tanzania are still lacking adequate infrastructures and services for ensuring fish quality, such as hygienic landing centres, electric power supply, potable water, roads, ice, ice plants, cold rooms, refrigerated transport and appropriate processing and storage facilities (Froukje *et al.,* 2020). Tanzania being one of the tropical countries is associated with tropical temperatures, this shortcoming, can result in high post-harvest losses, as fish can spoil in the boat, at landing, during storage or processing, on the way to the market and while awaiting to be sold. Studies have also indicated that in Africa, post-harvest losses can go up to 20 to 25% and spoilage can account for more than 70% of the loss (Akande and Diei-Ouadi, 2010, Froukje *et al.,* 2020). Losses are also qualitative with products deterioration entailing losses of nutritional value and risks for consumers in relation to food safety. Throughout the world, postharvest fish losses are a major concern and occur in most fish distribution chains.

In addition to that, studies reveals further that greater attention has been focusing on the loss in the monetary value of fish, which is generally not necessarily a result of loss of fish as food, but a downgrading in first-sale value of fisheries products (Maulu *et al.,* 2020). The losses in product value are driven by loss of intrinsic quality of fishery products due to deterioration with fish sold for lower than optimum price; and by market forces when for instance, landings exceed demand, forcing operators to sell their products at a price that is far below expectations (Getu *et al.,* 2015). Balanced supply is critical in the case of small pelagic fisheries that are subject to high variations depending on seasonal abundance of the targeted resources as in the case of Lake Victoria fisheries.

Food losses also undermine the adaptive capacities of vulnerable populations to cope with climate change through decreased food availability and reduced income. Moreover, food losses could further increase due to more frequent and intense climate variability and associated outbreaks of pests and diseases (FAO, 2017) that similarly forces use of agrochemicals in agriculture rendering their accumulation in aquatic environment.

Small-scale fisheries have greater potential of incurring greater losses compared with large-scale fisheries (FAO, 2014; Ward and Signa, 2017); this is due to their structural shortcomings. Like any other food system, losses of fish affect food security, thus the socio-economic impact of post-harvest losses is significantly higher for small-scale fishing communities because the post-harvest domain comprises several activities at all stages of the value chain, including handling fish on board, unloading, processing, storage and distribution (Kitinoja, 2016). Such activities are vital to

fishers' livelihoods and provide employment to many rural people including women.

The post-harvest losses that occur in the fish value chain that result into household economic losses especially for small-fish processors necessitates use of different chemicals such as pesticides to prevent fish spoilage and thus minimize the losses. This study was therefore conducted in Lake Victoria to assess whether post-harvest losses on the Nile perch value chain are important drivers of using chemical pesticides in fish storage. The results obtained from this study could significantly enable identification of food losses and waste indicators that could therefore inform policies that can improve the efficiency of the value chain, change the behavior of various actors in the fish value chain to reduce waste or encourage a better use of fish products and by-products.

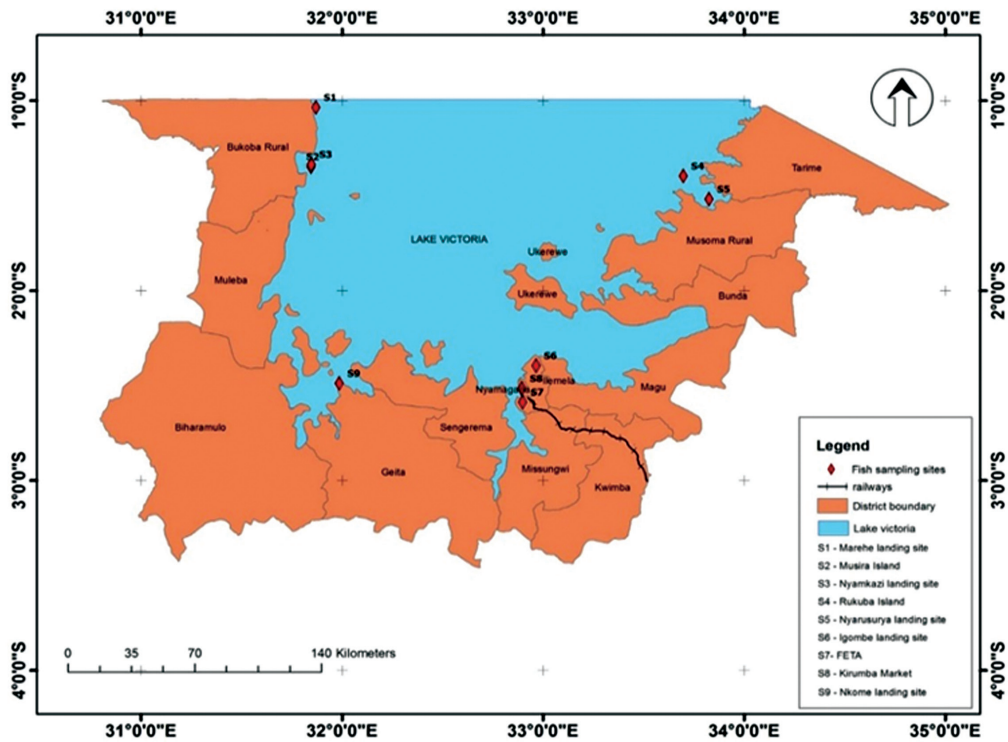


**Figure 2: Tanzanian side of Lake Victoria and fish sampling points**

## Materials and methods

### Description of the study area

The study was carried out on the Tanzanian side of Lake Victoria comprising four regions; Mwanza, Mara, Kagera and Geita (Fig. 2). Lake Victoria is a trans-boundary lake that is shared between Tanzania (51%), Uganda (43%) and Kenya (6%). It is the World's second largest lake with an approximated total surface area of 68,800 km$^2$ after Lake Superior that is located in North America. The lake supports one of the World's most productive inland fisheries of commercial species such as Nile perch and other species (Wenaty *et al.,* 2019a).

### Nile perch and products sampling

Nile perch as a major commercial fish species commonly found in Lake Victoria were sampled for organochlorine pesticides analysis from nine sampling stations that are nationally designated in four regions on the Tanzanian side of Lake Victoria, namely; Mwanza, Geita, Mara and Kagera.

One eighty fresh Nile perch samples that is twenty samples per site were collected from randomly selected fishermen at landing sites along Lake Victoria between May 2016 and August 2018 consecutively. The weights and

lengths of the sampled Nile perch samples were determined using a beam balance and a ruler respectively. The samples were stored in a cool box at a temperature of 4°C and transported to the laboratory for deep freezing at -18°C until the time of extraction.

Sixty samples of each of the Nile perch products (240 samples in total per sampling regime) that are processed to feed the domestic and regional markets (salted- sundried, smoked, trims and deep-fried products) were collected from Kirumba International fish market for OCPs analysis. The Kirumba International Fish Market was purposively selected out of other markets in Lake Victoria because it is the largest fish market in the zone that collects fish products from all other regions making up the Tanzanian side of Lake Victoria. It is a focal point where fish products for domestic, regional and international markets can be obtained.

**Fish products preparation and quality of analytical reagents**

Samples preparation was performed at the National Fish Quality Control Laboratory (NFQCL) in Mwanza, Tanzania. All reagents and glassware were purchased from local suppliers in Tanzania and were of analytical grade. Samples extraction and cleanup for determination of organochlorine pesticides was effected using a modified QuEChERS procedure as explained by Anastassiades *et al.* (2003) at the National Fish Quality Control Laboratory in Mwanza, Tanzania.

Three samples of almost the same size and weight (Kasozi *et al.,* 2006) from the same sampling location were pooled and homogenized to form a single composite sample according to Polder *et al.* (2014). Thirty grams of each sample was measured in triplicates (3 x 30 g) and ground using a motor and pestle to homogenize. Fifteen grams of composite samples were transferred into 100 mL centrifuge tubes. Thereafter, 2.5 g of sodium bicarbonate ($NaHCO_3$), 60 mL of ethyl acetate and 15 g of anhydrous $Na_2SO_4$ were added and placed in a shaker to homogenize for 10 min. The supernatants were transferred into 15 mL centrifuge tubes containing 0.125 g of Primary Secondary Amine (PSA) and 0.75 g of anhydrous $MgSO_4$ (Anastassiades *et al.,* 2003). The mixture was centrifuged at 2500 rpm for 20 min and left to separate for further 10 min. The resulting supernatants (2 mL) were transferred into vials and transported under cold conditions to Denmark Technical University (DTU), Division of Food Analytical Chemistry for GC analysis.

**Analytical Quality Control and Limits of Detection (LODs)**

Blanks and standards were run every after five samples in order to maintain the quality of analytical results. The limits of detection (LODs) were calculated as concentrations whose peaks were three times the peaks of signal to noise (S/N) ratio whereas the corresponding limits of quantification (LOQs) were calculated as concentrations using the peaks that were ten times the peaks of signal to noise (S/N) ratios.

**Chemical Analysis**

The chemical analysis was performed at the laboratory of Food Analytical Chemistry, Technical University of Denmark (DTU) in Denmark. The samples of fish collected were analyzed for 21 OCPs namely; p, p-DDT, o, p-DDT and metabolites p, p-DDE and p, p-DDD, α–HCH, β–HCH, γ–HCH (lindane), HCB, Heptachlor, Heptachlor epoxide, Aldrin, Dieldrin, Endrin, Isodrin, α–Endosulfan, β-endosulfan. Endosulfan sulfate, Oxychlordane, γ– Chlordane, α– Chlordane and Transnonachlor. Most of the studied compounds are listed in the Stockholm Convention on POPs for initial elimination and reduction in use because of their effects on environment as well as living organisms.

**Detection and quantification of OCPs using Gas Chromatography**

Separation and detection of OCPs were performed on a Hewllet Packard Gas Chromatography (Agilent 6890 Series gas chromatography system; from Agilent Technologies) equipped with an autosampler (Agilent 7683 Series; from Agilent Technologies) as described by Wenaty *et al.* (2019a, b). For optimum separation, a 1 m long pre – column was connected to a dual capillary column system with columns of different

polarity and selectivity (Chrompac 7443 CP–sil 5CB and J&W 122–1762 DB-17), Nominal length 50 m & 60 m respectively, 0.25 mm ID, 0.25 µm film thickness) and coupled to two 63Ni electron capture detectors (Agilent 6890 ECD). Specifications for the GC conditions were: Injector temperature: 280°C; injection volume: 2 µL; injector mode: splitless; purge flow: 42 ml/min; purge time: 0.60 min; carrier gas: Helium; constant flow: 2.0 mL/min and 1.3 mL/min respectively and make up gas: Nitrogen. The temperature programme was 90°C held for 2.0 min; 30°C/min increased to 170°C held for 7.5 min; 2.0°C/min increased to 185°C; 3.0°C/min increased to 220°C held for 15 min; 3.0°C/min increased to 255°C held for 2 min and 5.0°C/min increased to 280°C held for 10 min. The detector temperature was 300°C.

**Data Analysis**

Descriptive statistics were used to deduce the minimum, maximum, mean concentrations and standard deviations of the detected OCPs and data were further analyzed using SPSS Version 16. Data on OCPs concentration were presented as mean ± SD. ANOVA was used to compare concentrations between different Nile perch products and the means were separated using Duncan's Multiple Range Test. In data processing, the concentrations of OCPs in samples below the limit of detection (<LOD) were treated as zero. Significant difference was declared at $p<0.05$ for all analyses.

**Results and discussion**

The mean concentrations of organochlorine pesticides in fresh Nile perch muscles and processed Nile perch products are presented in Table 1. The results revealed that 10 out of 21 OCPs that were considered in this study were present in different Nile perch products at low concentrations.

The study revealed the presence of only four (β-HCH, HCB, Dieldrin and Aldrin) out of 21 organochlorine pesticides that were investigated in fresh muscles of Nile perch. The lowest concentration of OCPs in fresh fish muscles was 0.20 µg/kg (HCB) while the highest concentration was 0.40 µg/kg (Dieldrin). Four OCPs (α-HCH, Lindane, HCB and p, p-DDE) were also detected in salted- sundried products of Nile perch (Kayabo) at low levels.

In the salted- sundried products, α-HCH was detected at its lowest concentration of 0.54 µg/kg whereas p, p-DDE was the highest in terms of concentration being detected at a level of 2.02 µg/kg. In fish trims, only p, p-DDE was detected at a concentration of 1.74 µg/kg whereas other OCPs were below their limits of detection (<LODs) as indicated in Table 1.

The results indicated further that, nine (α- HCH, β-HCH, Lindane, HCB, Dieldrin,

**Table 1: Mean concentrations (µg/kg) of organochlorine pesticides in Nile perch its products from Lake Victoria**

| Pesticides | Fresh muscles | Kayabo | Trims | Smoked | Deep-fried | MRL (FAO, 1997) |
|---|---|---|---|---|---|---|
| α-HCH | <LOD | 0.54±0.02 | <LOD | 0.39±0.01 | <LOD | 300 |
| β-HCH | 0.30±0.10 | <LOD | <LOD | 1.43±0.18 | <LOD | 300 |
| Lindane | <LOD | 1.15±0.05 | <LOD | 0.99±0.10 | 1.00±0.38 | 300 |
| HCB | 0.20±0.01 | 0.66±0.10 | <LOD | 1.67±0.40 | <LOD | 200 |
| Dieldrin | 0.40±0.10 | <LOD | <LOD | 0.70±0.10 | <LOD | 300 |
| Aldrin | 0.20±0.02 | <LOD | <LOD | <LOD | <LOD | 300 |
| p, p-DDE | <LOD | 2.02±0.11 | 1.74±0.71 | 1.10±0.23 | 2.20±0.16 | 300 |
| α-endosulfan | <LOD | <LOD | <LOD | 0.65±0.10 | <LOD | NE |
| Oxychlordane | <LOD | <LOD | <LOD | 0.39±0.03 | <LOD | NE |
| α-chlordane | <LOD | <LOD | <LOD | 0.89±0.02 | <LOD | NE |
| | n = 60 | n = 60 | n = 60 | n = 60 | n = 60 | |

*<LOD: Below Limit of Detection; NE: Not Established*

p, p- DDE, α- endosulfan, Oxychlordane and α- chlordane) out of 21 OCPs were found to be present in smoked fish products at a concentration ranging between 0.39 µg/kg (α-HCH) and 1.67 µg/kg (HCB). Other OCPs were below the limits of detection (<LODs) and that smoked products were heavily contaminated by large number of OCPs compared to other products.

Furthermore, two out of the 21 OCPs that were considered for this study were detected in deep- fried products of Nile perch. The lowest residual concentration was 1.00 µg/kg (Lindane) whereas the highest level was 2.20 µg/kg (p, p-DDE) which was detected in all four processed fish products at significantly higher levels compared to other persistent OCPs.

The levels of HCHs that were detected in fresh Nile perch muscles and its processed products in this study were far lower than those that were detected in a similar study by Ssebugere *et al.* (2014a, b) in fish from the Ugandan side of Lake Victoria in which HCHs were in a range from 5.7 µg/kg to 34 µg/kg. There were slightly higher levels of lindane (γ-HCH); which is a parent compound than the other two isomers α-HCH and β-HCH in Nile perch and products.

This suggests current application of the pesticide in the catchment area (Wenaty *et al.,* 2019a, b). The study indicated further that, there were slightly higher levels of β-HCH than α-HCH in Nile perch and its respective products. This is attributed to the fact that the former is more persistent in the environment than the later as reported in the previous studies (Polder *et al.,* 2014; Wenaty *et al.,* 2019a). The levels of HCB in processed Nile perch products was approximately 9 folds higher than that in fresh Nile perch muscles. According to URT (2005) and Wenaty *et al.* (2019a), there is no evidence over the use of HCB in Tanzania and Lake Victoria Zone in particular, thus its presence in Nile perch and its processed products is due to long range atmospheric transport and environmental persistence.

The results show further high levels of Dieldrin than Aldrin in fresh muscles of Nile perch and processed products. The levels of Dieldrin detected in processed products were approximately two times the levels of the same that was detected in fresh muscles of Nile perch. Studies have indicated that Aldrin decomposes in the presence of bacteria and sunlight in the environment to Dieldrin thereby increasing the concentration of Dieldrin in environmental samples (Kasozi *et al.,* 2006).

For the DDT isomers that were considered (p, p-DDT, o, p-DDT, p, p-DDE and p, p-DDD), only p, p-DDE as a decomposition product was detected in all the four processed Nile perch products but not in the fresh muscles of Nile perch. All other isomers were below their limits of detection (<LODs). The residual levels of p, p-DDE ranged from 1.10 µg/kg in smoked fish products to 2.20 µg/kg in deep-fried fish products. High levels of DDTs in deep- fried fish products than other products is an indication of misuse of the pesticide in the study area since as a rule of thumb, low levels of the pesticides could be anticipated in deep-fried fish products. This is due to the fact that at higher processing temperatures, cooking oil acts as an extracting solvent extracting much of the pesticides from the product (Witczak, 2009; Wenaty *et al.,* 2019b). The other decomposition product, p, p-DDD was not detected in any of the Nile perch samples examined indicating that the decomposition of p, p-DDT as a parent compound in fish species is an aerobic process that produces DDE rather than DDD due to presence of oxygen (Kasozi *et al.,* 2006; Wenaty *et al.,* 2019c). The ortho, para- DDT (o, p-DDT) as another isomer of the parent compound was as well not detected in any of the Nile perch products. This is attributed to its small proportion in the DDT mixture that comprises of approximately 77% p, p-DDT, 13% o, p-DDT with the decomposition products; p, p-DDE and p, p-DDD making up the difference (Afful *et al.,* 2013).

For the three-endosulfan isomers that were considered in the current study; α-endosulfan, β-endosulfan and the degradation product which is endosulfan sulfate, only α-endosulfan was detected at low concentrations in smoked fish products. The levels of endosulfans in all other products were below their limits of detection (<LODs). The presence of α-endosulfan in Nile perch products indicates recent exposure of the

products to the chemical through the food chain. However, the other isomer; β-endosulfan was not detected; this observation is attributed to the variation of the two components in the endosulfan mixture which consist of approximately 70% α-endosulfan and 30% β-endosulfan with endosulfan sulfate being the decomposition product (Afful *et al.,* 2013). However, the concentrations of OCPs in fresh muscles of Nile perch as well as in processed products were far below the maximum recommended limits (MRLs) which are set for fish and fish products implying that the Nile perch and its processed products from Lake Victoria are safe for human consumption in regards to the assessed chemical contaminants.

Comparing the levels of the detected OCPs in fresh fish muscles of Nile perch to those in processed Nile perch products, the study revealed significantly higher levels of OCPs in processed fish products that are intended for domestic and regional markets than in fresh fish muscles. This suggests a probable use of pesticides in the Nile perch value chain to preserve the products and thus adding to the overall concentrations. According to FAO (2011), post-harvest losses in the fish value chain in SSA exceeds 85% and thus fisher folks have been devising different mechanisms including use of chemicals to cut down these huge monetary and nutritional losses.

## Conclusion and recommendations

This study assessed the levels of organochlorine pesticides residues in fish and fish products from Lake Victoria in Tanzania. Based on this study, smoked fish products were observed to be highly contaminated with OCPs followed by kayabo and fresh fish muscles. The trims were the least contaminated compared to all fish products studied with only one OCP detected followed by deep-fried fish products which were found to be contaminated by two organochlorine pesticides. The levels of OCPs in Nile perch and its products were observed to be very low compared to MRLs set for fish and fish products indicating their safety for human consumption. It was further noted that the levels of OCPs in processed Nile perch products were far higher than the corresponding levels in fresh muscles of Nile perch. Moreover, high levels of OCPs in processed Nile perch products than in fresh muscles of Nile perch is an indication of misuse of pesticides in the study area. It is therefore possible that the post-harvest losses in the Nile perch value chain are drivers of using pesticides for preservation of fish products to prevent the losses that are likely to occur and important contributors to high levels of organochlorine pesticides in the Nile perch value chain. Therefore, fisher folks need to be trained on appropriate post-harvest management practices that do not involve use of chemicals in the Nile perch value chain.

## Conflict of Interests

The authors have not declared any conflict of interests.

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