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Putting small fish on the table: the underutilized potential of small indigenous fish to improve food and nutrition security in East Africa

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Abstract
Sub-Saharan Africa has a high prevalence of food insecurity. Small pelagic fish such as Silver cyprinid (*Rastrineobola argentea*) which is indigenous to Lake Victoria, can be a nutritious animal sourced food that contributes to a more nutrient dense diet. Potential sustainable catch of Silver cyprinid is estimated at 2 million tonnes yearly, which is four times the amount of the current catch. Whole sun-dried Silver cyprinid was purchased from several markets in Kenya and analysed for nutrient composition, microbial counts and metal content. The results show that utilizing the whole potential catch of Silver cyprinid would provide a significant daily source of vitamin B12, calcium, zinc and iron to the roughly 33 million people living in the Lake Victoria basin. Heavy metal concentration appears to be low, but other food safety aspects like microbial counts call for value chain improvements. We conclude that the underutilized potential of sun-dried Silver cyprinid could substantially contribute to fight malnutrition and food insecurity by providing an affordable nutrient dense animal sourced food to a large number of people. It also highlights the need to improve the value chains to increase the safety of these products.

Keywords Animal sourced foods · Small fish · Food security · Food safety · Nutrition · Sub-Saharan Africa · Lake Victoria · *Rastrineobola argentea*

1 Introduction

Food insecurity and malnutrition are still prevalent in many places of the world. In 2021, 30% of the population in East Africa were considered undernourished and two-thirds faced moderate to severe food insecurity (FAO et al., 2022; ACPF, 2019). Abating malnutrition is high on the list of the United Nations Sustainable Development Goals (SDG), where SDG2, Zero Hunger, aims to "end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (indicator 2.1) (United Nations, n.d.).

Fish, the most abundant wild caught animal sourced food, plays an important role for food and nutrition security and is increasingly recognised as key in addressing malnourishment. Recently, Hicks et al. (2019) modelled the global spatial patterns of nutrient concentrations in marine fish species and compared nutrient yields to the prevalence of micronutrient deficiencies in riparian coastal populations. However, approximately 25% of the global fish demand is supplied by freshwater fishery and freshwater aquaculture (Dugan et al., 2007) providing food for millions of people worldwide. In East Africa more than 80% of the aquatic food is coming from freshwater systems (Simmance et al., 2022) and small fish species now comprise 75% of the total African inland catches (Kolding et al., 2019). Nevertheless, freshwater fish stocks can be considered the world's forgotten fishes (WWF,

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2021). The fishery on freshwater fish stocks and its potential for a transformation towards a sustainable and healthy food system is neglected in the global strategies to meet SDG2 (David, 2007; Lynch et al., 2020).

One example of an underutilized fishery in East Africa is the case of the *Rastrineobola argentea* (Silver cyprinid), a small (max length 8.0 cm) fish species from Lake Victoria (locally called omena (Kenya), dagaa (Tanzania) or mukene (Uganda)), which is traded all over the East African region (Kolding et al., 2019; Ojwang et al., 2014). This small zooplanktivorous fish species is at a low trophic level with an estimated biological production of approximately 5.5 million tonnes per year and has the potential for a sustainable yield of more than 2 million tonnes per year, while only a quarter is currently harvested (Fig. 1) (Kolding et al., 2019). In Sub-Saharan Africa, small fish like the Silver cyprinid are widely affordable, typically sun-dried and eaten whole, with heads, bones, and viscera included. They may represent a concentrated source of multiple essential nutrients, in contrast to large fish which are usually not eaten whole but fillets only (Hasselberg et al., 2020; Longley et al., 2014; Tacon & Metian, 2013).

The Silver cyprinid is traditionally processed by sun-drying near to the landing site to prevent rapid spoilage, to increase storage time for availability in the lean season, and to enable non-chilled distribution over longer distances (McHenry et al., 2016). However, environmental and value chain induced contaminants, such as heavy metals and poor hygiene might impair the safety and nutritional value of the product (Roesel & Grace, 2015). Little data is available on combined analysis of macro- and micronutrients, and food safety threats in processed small fish like Silver cyprinid, and there is no data estimating the potential contribution of this or similar freshwater fisheries to nutritional demands of the population in the Lake Victoria region.

This study provides primary data on the nutritional value (vitamins, minerals as well as the amino acid and fatty acid profile) and potential hazards (including chemical contaminants, microbial hygienic condition) of sun-dried Silver cyprinid sampled from local markets in Kenya. The data on

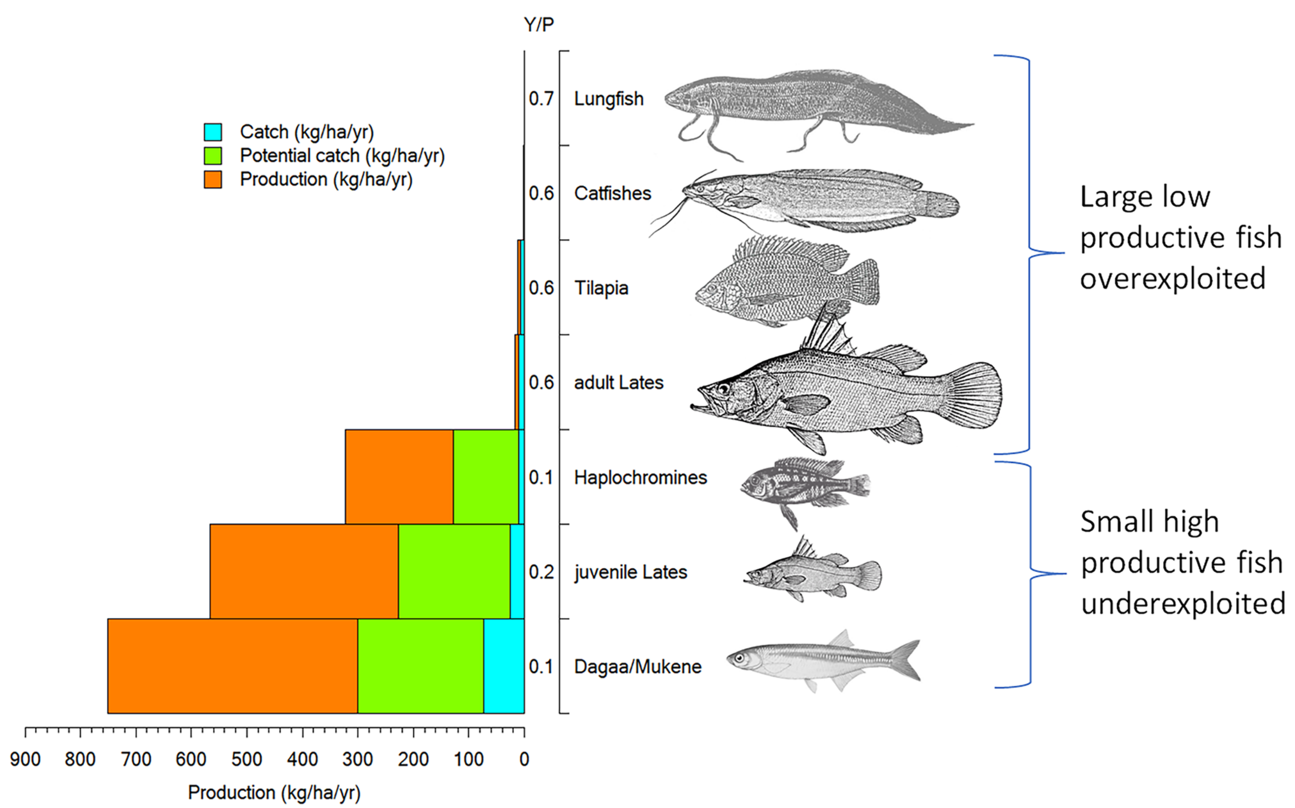

Fig. 1 Production and exploitation of fish species in Lake Victoria. Overlaying bars show the annual total biological production (orange), potential sustainable catch (green), and current catch (blue) all in kg/ha/yr of commercial fish species from Lake Victoria, East Africa. C/P (current catch/total biological production) indicates the exploitation rate. Potential sustainable catch is based on a sustainable exploitation rate of 0.4 (40% of total biological production) (Pikitch et al., 2014), while higher exploitation rates are considered overexploited. Large fish are mostly fully, or overexploited in Lake Victoria, while small fish have a significant underutilized potential as food resource, which shows the highly unbalanced current fishing pattern (Zhou et al., 2019). Exploitation of the Silver cyprinid is currently only 10% of a very high total biological production of around 750 kg/ha/yr. Data used are from Natugonza et al. (2016)

nutritional value were further used to estimate the potential of sun-dried Silver cyprinid to meet the nutritional demand of the population in the Lake Victoria basin.

2 Methods

2.1 Sampling

Sun-dried, whole *Rastrineobola argentea* (Silver cyprinid) was collected from eight different markets in different cities in Kenya from 23rd of November 2019 to 3rd of December 2019. Samples were collected at markets in Kisumu, Mbita, Busia, Eldoret, Kakamega, Bondo, Nakuru, and Nairobi. A local scientist from the Kenya Marine and Fisheries Research Institute (KMFRI) accompanied the team during sampling, assisted in species identification and as a translator.

Five different market stalls were sampled at each location. After arrival at the market, the number of market stalls selling sun-dried Silver cyprinid were counted. For a homogenous distribution of sampled market stalls, the total number of market stalls was divided by 5 to determine the n^{th} market stall to be sampled. The first market stall to be sampled was randomly selected from n-1 market stalls using the phone application "Random Number Generator Plus" (RandomAppsInc, Fremont, CA, USA) and then every n^{th} market stall was sampled. As one market stall sold more than one batch of sun-dried Silver cyprinid, both available batches were sampled separately. This sampling procedure resulted in a total of 41 samples.

Approximately 200 g of sun-dried Silver cyprinid was purchased at every sampled market stall. The amount of fish was measured by the seller using a tin can, which was the typical selling unit at the markets. The sun-dried Silver cyprinid was evenly distributed into two sub samples into sterile plastic bags, one for microbiological analysis and the other one for nutritional and heavy metal analysis. Samples were transported to the local KMFRI office and stored at 4 °C. The samples were packed in Styrofoam boxes with cooling elements and send to Germany or Norway via airfreight.

2.2 Microbiological analysis

After arrival in Germany, the samples were stored at 4 °C until homogenisation in a GRINDOMIX GM200 (Retsch GmbH, Haan, Germany) for 20 s at 4.000 rpm. Samples were then stored in plastic cups with screw-on lid (WMC Medical Consulting, Pulheim, Germany) at 4 °C until further analysis. The homogenised samples were rehydrated as described in ISO 6887-3:2003. An aliquot of 11 g was mixed with 22 g buffered peptone water (Mast Group, Bootle, United Kingdom) for 10 s in a peristaltic lab blender (Bag Mixer CC, Interscience, Saint Nom, France) and rehydrated at room temperature for one hour. Initial suspensions were prepared by adding 297 g of buffered peptone water and mixed in a peristaltic lab blender for 90 s.

2.2.1 Quantitative microbiological analysis

For quantitative colony counts, the initial suspension was diluted 10-fold in 0.85% saline/0.1% triptone diluent (Merck, Darmstadt, Germany). For aerobic and anaerobic total colony counts, 100 µL of the initial suspension and consecutive dilutions was spread on Columbia blood agar plates (Oxoid Deutschland GmbH, Wesel, Germany) and incubated at 30 °C for 72 h, either aerobically or anaerobically in anaerobic jars with AnaeroGenTM sachets (Oxoid Deutschland GmbH). Yeast and mould counts were analysed by plating 100 µL of the initial dilution and consecutive dilutions on yeast extract glucose chloramphenicol agar (Merck, Darmstadt, Germany), aerobically incubated at 30 °C for 72 h. To analyse coliform bacteria and *Escherichia coli* (*E. coli*) counts, 1 mL of initial suspension was spread on three plates and 100 µL of two consecutive dilutions were spread on BrillianceTM *E. coli*/coliform agar plates (Oxoid Deutschland GmbH) and incubated aerobically at 37 °C for 24 h. The analysis for presumptive *Bacillus cereus* was performed as described in ISO 7932:2004. One millilitre of the initial suspension was spread on mannitol egg yolk polymyxin agar (MYP, Merck, Darmstadt, Germany) and incubated aerobically at 30 °C for 24 h. Typical colonies were counted as *Bacillus cereus* group if they were positive for haemolysis and confirmed via Matrix Assisted Laser Desorption/Ionization- Time of Flight (MALDI-ToF, Bruker, Billerica, MA, United States of America) according to manufacturer´s protocol.

2.2.2 Qualitative analysis of *Salmonella* spp. and shiga-toxin producing *Escherichia coli* (STEC)

The analysis for *Salmonella* spp. was performed according to ISO 6579-1:2017. The initial suspension (see above) was incubated at 37 °C for 18 h aerobically. After incubation, three droplets (100 µL) of the pre-enrichment culture were inoculated on modified semi-solid Rappaport Vassiliadis agar (MSRV; Oxoid Deutschland GmbH, Wesel, Germany) and incubated at 42.5 °C for 24 h aerobically. Another 1 mL was added to 10 mL Mueller-Kauffman Tetrathionate Novobiocin broth (MKTTn; Oxoid Deutschland GmbH, Wesel, Germany) incubated at 37 °C for 24 h aerobically. A 10 µL loop of the incubated MKTTn and MSRV was spread on xylose lysine deoxycholate agar plates (XLD, Merck, Darmstadt, Germany) and Gassner agar plates (GAS, sifin, Berlin, Germany). Both plates were incubated aerobically at 37 °C for 24 h. Presumptive colonies were sub-cultured for confirmation.

The presence of shiga-toxin producing *E. coli* was analysed following the method by Pavlovic et al. (2010). The overnight enrichment culture of the initial suspension was spread on triptone bile X-glucuronide agar (Oxoid Deutschland GmbH) plates and incubated at 37 °C for 24 h aerobically. After incubation, a run-off was prepared using 1 mL of water. DNA was extracted by treating the run-off at 95 °C for 10 min followed by centrifugation. The PCR was performed using 100-fold dilution of the extracted DNA and the protocol described by Pavlovic et al. (2010).

2.3 Nutritional analysis

Nutritional analysis was performed at the Institute of Marine Research (IMR) in Norway using methods accredited to ISO 17025:2005. The method for iron is a validated method, but not accredited. All methods were previously described in detail by Moxness Reksten et al. (2020). Before analyses, the samples were homogenised in a food processor (Braun 3210, Neu-Isenburg, Germany) and depending on the analysis stored either at -20 °C (freeze dried samples) or -80 °C (wet samples).

2.3.1 Crude protein, fat and fatty acids

For analysis of crude protein content, samples were burned in a combustion oven containing pure oxygen at 830 °C and nitrogen was detected with a thermal conductivity detector (TCD). Assuming an average nitrogen (N) content in protein of 16%. The protein content was calculated using following equation:

$$\mathrm{N\ g/100g} * 6.25 = \mathrm{protein\ g/100g} \tag{1}$$

Fat content was determined via extraction with ethyl acetate and weighing the residual after evaporation of the solvent. Fatty acid content was determined via gas liquid chromatography. Methyl esters were separated on a capillary gas column (CP-sil-88, 50 m WCOT, ID:0.32) and peaks were identified by retention time using standard mixtures of methyl esters (Nu-Check, Eylan, USA) and fatty acid content was calculated using a 19:0 methyl ester internal standard (Moxness Reksten et al., 2020).

2.3.2 Vitamin composition

For analysis of vitamins samples were saponified and the unsaponified material was extracted. Vitamin A1 (sum all trans-retinol and 13-, 11-, 9-cis retinol) and A2 (4,4 didehydro-all-trans retinol) were determined using high-performance liquid chromatography (HPLC; normal phase) and Photo Diode Array detector (PDA). Retinol was calculated using an external calibration (standard). For vitamin D3 analysis the extracted unsaponified material was purified in a preparative HPLC column. Vitamin D2 (ergocalciferol) and vitamin D3 (cholecalciferol) were pooled and determined via ultraviolet (UV) detector. Concentration of vitamin D3 was calculated using vitamin D2 as internal standard (Reksten AM, accepted). Vitamin B12 (cobalamin) was extracted by autoclaving the samples in acetate buffer and followed by mixing with growth medium. *Lactobacillus delbrueckii* ATCC 4797 was added to the mixture and incubated at 37 °C for 22 h. Concentration of vitamin B12 was determined by comparison to the growth rate of *Lactobacillus delbrueckii* in known concentration of vitamin B12 by turbidimetric reading (optical density, OD, v/575 nm) (Moxness Reksten et al., 2020).

2.3.3 Analysis of minerals and trace elements

After wet digestion in a microwave oven, cadmium, total arsenic, total mercury, lead, calcium, selenium, zinc, and iron were analysed by Inductively Coupled Plasma-Mass Spectrometry (iCapQ ICP-MS, ThermoFisher Scientific, Waltham, MA, USA) (Moxness Reksten et al., 2020). Inorganic arsenic was analysed using Agilent 1260 Infinity II Series BIO Inert HPLC with an autosampler (Santa Clara, CA, USA) coupled with an Agilent 7900 ICP-MS instrument and quantified with external calibration (Sloth et al., 2005). Iodine was analysed using ICP-MS analysis after extraction with tetramethylammonium hydroxide (TMAH) (Moxness Reksten et al., 2020). Fluoride was determined using fluoride ion-specific electrode after dry combustion (Kjellevold Malde et al., 2001).

2.4 Calculation of the nutritional value and potential exposure

Contribution to the dietary reference values were calculated using the population reference intake (PRI) values given by the European Food Safety Authority (EFSA) and if values for PRI were not available, the reference values for an adequate intake (AI) were used (Table 1) (European Food Safety Authority, 2017). For PRI or AI values for adults above the age of 18 were used as reference. In cases with different recommendations for females and males, the values for women of reproductive age was used for calculations (Table 1). Further, for the PRI of zinc phytate intake has to be considered. For this study 900 mg/day phytate level was used as this value are closest to the RNI of zinc provided by FAO for a diet with low bioavailability (Human Vitamin and Mineral Requirements, Report of a joint FAO/WHO expert consultation Bangkok, Thailand, 2001).

Table 1 Dietary reference values for different nutrients (European Food Safety Authority, 2017)

Nutrient	Population reference intake (PRI)	Adequate intake (AI)
Calcium	950 mg/day	n.a.
Zinc	11 mg/day[a]	n.a.
Iron	16 mg/day	n.a.
Iodine	n.a.	150 µg/day
Vitamin A	650 µg RE/day	n.a.
Vitamin B12	n.a.	4 µg/day
DHA & EPA	n.a.	250 mg/day

[a]assuming a phytate intake of 900 mg/day

n.a. not applicable, *RE* retinol equivalents, *DHA* docosahexaenoic acid, *EPA* eicosapentaenoic acid

Table 2 Tolerable weekly intake (TWI) and benchmark dose limits (BMDL01)for mercury (Hg), lead (Pb), arsenic (As),and cadmium (Cd) ((EFSA Panel on Contaminants in the Food Chain, 2009, 2010, 2012; European Commission Panel, 2009)

Metal		TWI [µg/kg bw per week]	BMDL01 [µg/kg bw per day]
Cadmium		2.5	n.a.
Mercury[a]	Methylmercury	1.3	n.a.
	Inorganic mercury	4.0	n.a.
Lead		n.a.	0.63
Inorganic arsenic		n.a.	0.3-8.0[b]

[a]the analysis in this study did not differentiate between methylmercury and inorganic mercury. For all calculations it was assumed all found mercury was methylmercury

[b]the lower limit (0.3 µg/kg bw) was used for all further assumptions and comparisons

TWI Tolerable Weekly Intake, *BMDL01* benchmark dose (lower confidence limit), *n.a.* not applicable, *bw* body weight

Along with the Kenyan Food composition table (FAO & Government of Kenya, 2018a), the Kenyan Food Recipes (FAO & Government of Kenya, 2018b) has been published, where two recipes for sun-dried Silver cyprinid (referred to as omena) are described. An average portion size per serving according to these recipes is 30 g of sun-dried fish. All calculations regarding percentage of dietary reference values or exposure to chemical contaminants in this study were calculated assuming an average portion size of 30 g per serving and consumption of one serving per day. The calculations of estimated exposure to chemical contaminants from one portion (30 g of sun-dried Silver cyprinid) was performed using concentration values of the 25th percentile and 75th percentile of the respective contaminant found in processed Silver cyprinid (data from this study). These values were compared to the tolerable weekly intakes or benchmark dose limits from the EFSA (see Table 2) (EFSA Panel on Contaminants in the Food Chain, 2009, 2010, 2012; European Commission Panel, 2009).

2.5 Calculations of the number of potential beneficiaries

According to the European Union authority, a food is regarded as a "significant source of a nutrient" if it covers at least 15% of the daily recommended intake per 100 g, or per portion (Regulation No. 1169/2011 on food information to consumers). Based on the recommended daily intake, the number of beneficiaries who could be provided with a serving of processed Silver cyprinid considered significant for a nutrient was calculated. The population of the Lake Victoria basin area in Kenya, Tanzania and Uganda was estimated to be 33 million people in 2018 extrapolated from the data and annual growth rates given by the United Nations Environment Programme (LVEMP) (2007). Data for potential sustainable annual catch of 2.0 million tonnes fresh Silver cyprinid and actual annual catch of around 0.5 million tonnes fresh fish per year was taken from Kolding et al. (2019). To match the measured nutrient content in sun-dried Silver cyprinid, as measured in this study, a water reduction factor was included in the calculation. This factor considers the weight loss during the drying process from the weight of fresh fish to the weight of dried fish product. In the case of Silver cyprinid a factor of water weight loss of 3.262 (70% loss) was used based on previous findings in which 3.71 kg fresh fish resulted in 1.137 kg dried fish (Oduor-Odote et al., 2010). Post-harvest losses of Silver cyprinid have been previously described by Akande and Diei-Ouadi (2010) as up to 40%. Others reported post-harvest losses of about 56% (Kristofersson & Ibengwe, 2012) leading to a scenario with estimated 60% post-harvest losses. The calculations were performed with both 40% and 60% post-harvest losses assuming all the catch is used for human consumption.

2.6 Data management and calculations

All calculations and figures were done in Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington, USA), RStudio 1.3.1093 (RStudio In., Boston, MA, USA) and R 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria).

3 Results

3.1 Nutritional value of sun-dried silver cyprinid

Like many other animal sourced foods, the analysed samples of the sun-dried whole Silver cyprinid were high in protein and fat, showing a median (percentile 25-percentile

75) protein content of 61 (59–63) g/100 g processed whole fish and a median (percentile 25-percentile 75) fat content of 12.9 (11.9–14.1) g/100 g (see 6.).

A common portion of 30 g sun-dried Silver cyprinid covers 91% of the daily population reference intake (PRI) of calcium, and 470% and 250% of the adequate intake (AI) for adults of B12 and DHA + EPA, respectively (Fig. 2). On average, one portion contained a significant amount of zinc and iron, providing 61% and 56% of the PRI. A large variation between the samples ($n = 41$) was found for some of the micronutrients, where iron, iodine and vitamin A showed the largest inter-sample variability (see 6.).

3.2 Potential hazards of sun-dried silver cyprinid at market level

3.2.1 Microbial hazards

The microbiological analysis of dried Silver cyprinid from the different markets showed that all analysed samples had elevated total colony counts (TCC) above 4.0 log colony forming units (CFU)/g exceeding the East African Standard (DEAS) limit values (Fig. 3). The values of aerobic TCC had a variation of more than three orders of magnitude from 4.8 to 7.9 log CFU/g. The counts of yeasts and moulds ranged from below the limit of detection of 2 log CFU/g to 7 log CFU/g. Nonetheless, the DEAS limit value for yeast and moulds of 5.0 log CFU/g was only exceeded in three samples of sun-dried Silver cyprinid. *Salmonella* spp. was not detected in any of the samples in this study. Shiga toxin-producing *Escherichia coli* were detected via PCR in sun-dried Silver cyprinid from 7 of the 41 sampled market stalls.

3.2.2 Chemical contaminants

The mean heavy metal concentration (mean ± SD) in sun-dried Silver cyprinid for cadmium (Cd), total mercury (Hg), lead (Pb) and total arsenic (As) was 0.04 ± 0.01 mg Cd/kg, 0.03 ± 0.01 mg Hg/kg, 0.07 ± 0.06 mg Pb/kg, and 0.52 ± 0.16 mg total As/kg, respectively.

One 30 g portion of sun-dried Silver cyprinid did not exceed the tolerable weekly intake (TWI) or benchmark dose (BMDL01) given by the EFSA (EFSA Panel on Contaminants in the Food Chain, 2009; EFSA Panel on Contaminants in the Food Chain, 2010; EFSA Panel on Contaminants in the Food Chain, 2012; European Commission Panel, 2009) for any of the analysed chemical contaminants (see Fig. 4). In alignment with the results of others that most

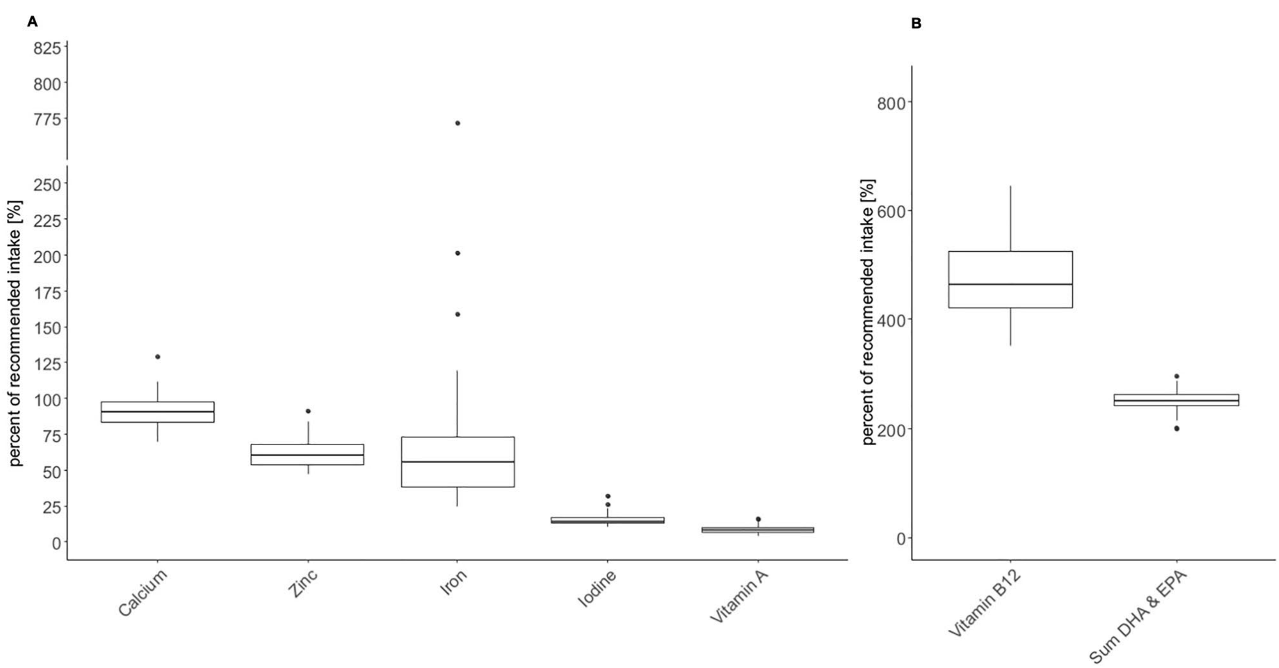

Fig. 2 Estimated contribution to the recommended daily nutrient intake by consumption of a common serving of sun-dried Silver cyprinid. Contribution of a 30 g portion of sun-dried whole Silver cyprinid to the population reference intake (PRI) of calcium, zinc, iron, and vitamin A and to the adequate intake (AI) of iodine (**A**) and the contribution to the AI of vitamin and the sum of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (**B**) (EFSA Panel on Dietetic Products & Allergies, 2010, 2014a, b, 2015a, b, c, d). Calculations for figure **A** and **B** are based on the analysis of 41 samples. Boxplots show the median (bold bar), the interquartile range (IQR) (25th percentile to 75th percentile); the whiskers represent observations within 1.5 times the IQR. Dots represent outliers (> 1.5 times IQR)

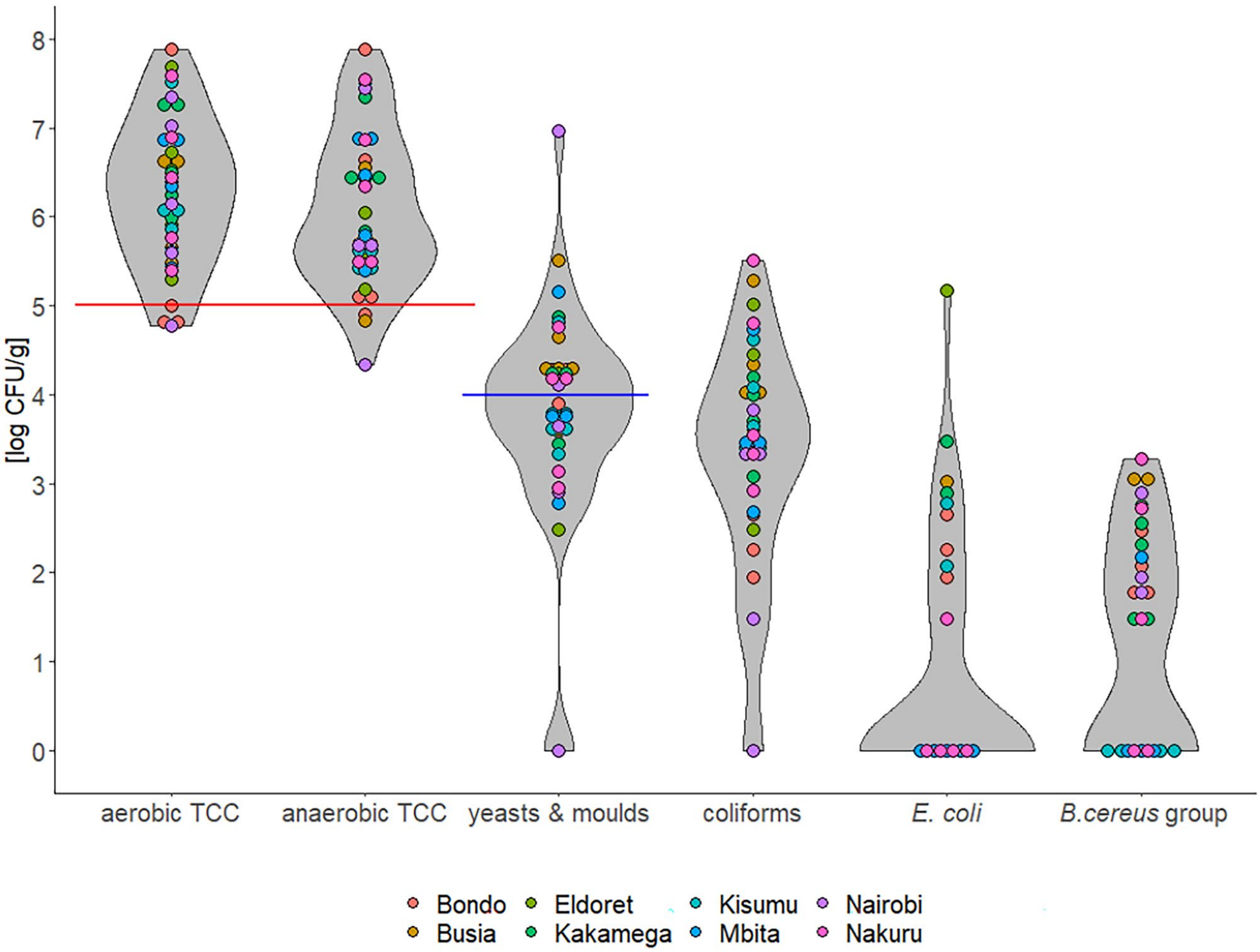

Fig. 3 Bacterial counts in sun-dried Silver cyprinid from different markets in Kenya. Sun-dried whole Silver cyprinid was purchased from different markets in Kenya and the results of bacterial counts are displayed as violin plots of $n=41$ samples. All samples below the limit of detection were added into the figure as zero. TCC = total colony count; CFU = colony forming units, *E. coli* = *Escherichia coli; B. cereus* group = *Bacillus cereus* group. Limit values of the East African Standard (DEAS 826:2014) are shown as lines, the blue line indicate the limit value for TCC at 4 log CFU/g and the red line indicate the limit value for Yeast and Mould at 5 log CFU/g. The coloured circles show the values of different samples. Samples in the same colour were taken from the same market

of the arsenic in fish are organic arsenic (Jia et al., 2018), the concentration of inorganic arsenic in sun-dried Silver cyprinid was below the limit of quantification of 0.007 µg/kg. Therefore, the exact intake of inorganic arsenic cannot be quantified, but the BMDL01 of 21 µg per day was not exceeded by a reasonable portion. For cadmium, mercury and lead a potential safe weekly consumption range (0.25–0.75 quantile), which would not exceed the respective TWI, was estimated as 675–833 g, 352–566 g, and 565–1260 g, respectively. Neurotoxicity caused by lead in children was addressed by applying the BMDL01 value at 0.5 µg/kg body weight (bw) per day (EFSA Panel on Contaminants in the Food Chain, 2010). Consumption of one portion of 30 g for a child of 20 kg body weight would result in an estimated intake range of lead of 0.087 (0.053–0.117) µg/kg bw.

3.3 Number of beneficiaries

A food item containing at least 15% of the recommended daily intake of a mineral or vitamin (see Table 1) per portion is considered a significant source (European Commission, 2011). Based on the results of this study, the median portion of sun-dried Silver cyprinid which is needed to reach 15% of the recommended daily intake for women of reproductive age is 1 g, 6 g, 9 g, and 19 g for vitamin B12, calcium, zinc, and iron, respectively. For these nutrients, 15% or more of the recommended daily intake for women of reproductive age could be covered by a portion of 30 g. For iodine and vitamin A, a portion size of 31 and 72 g, respectively, would be necessary to reach 15% of the recommended daily intake.

Potential sustainable annual catch of Silver cyprinid is estimated at 2 million tonnes fresh weight, which is four

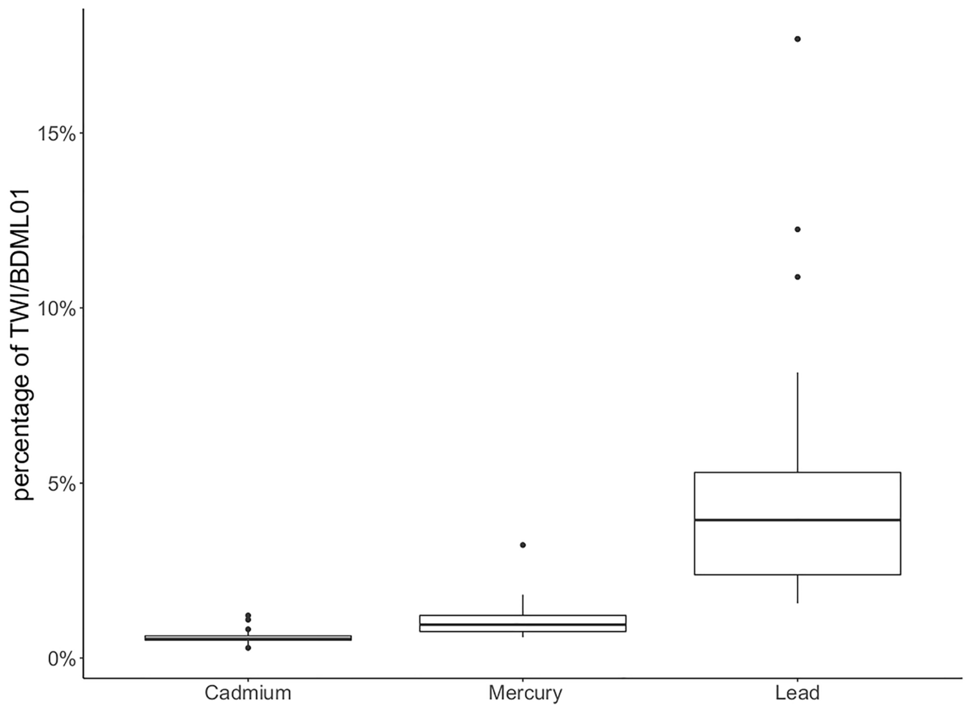

Fig. 4 Estimated intake of heavy metals from consumption ofsun-driedSilver cyprinid. Calculations for an estimated exposure were based on the consumption of one portion size of 30 g of sun-dried whole Silver cyprinid and a body weight of 70 kg. For cadmium and mercury, the TWI and for lead the BMDL01 was used as reference. Boxplots show the median (bold bar), the interquartile range (IQR) (25th percentile to 75th percentile); the whiskers represent observations within 1.5 times the IQR. Dots represent outliers (> 1.5 times IQR). TWI = Tolerable Weekly Intake; BMDL01 = benchmark dose (lower confidence limit)

times the amount of the current catch. Assuming that all the catch is subjected to human consumption it would be possible to provide a daily significant source of vitamin B12, calcium, zinc and iron to the estimated population of the Lake Victoria basin (Fig. 5).

4 Discussion

Lake Victoria in East Africa is the world's largest tropical lake and supports one of the largest freshwater fisheries, with annual landings of around one million tons (Kolding et al., 2019). The fishery is dominated by the small zooplanktivorous indigenous Silver cyprinid and the large, introduced predator, Nile perch, together constituting more than 80% of the total catch and 80% of total biological production (Fig. 1). Fishing effort has increased nearly exponentially since the 1970s, but neither the catches, nor the surveyed biomasses of the fish stocks have shown signs of decrease, except for the adult population of Nile perch and other large predators such as catfish and lungfish, which are considered overfished (Natugonza et al., 2016). The blame for the decreasing catch rates of adult Nile perch is consistently placed on the illegal fishery of juveniles and massive campaigns have been initiated to eradicate nets with small mesh sizes (Mpomwenda et al., 2021). The juvenile Nile perch and small fish species, including the haplochromine cichlids are together producing a total of around 11 million tons per year and are only lightly exploited with less than 10% of the total production (Fig. 1). These stocks alone could sustainably yield 3–4 million tons per year to a riparian human population suffering from chronic malnutrition (Kolding et al., 2019). Thus, allowing a shift in the current fishing pattern towards catching more small-sized, highly productive, lower trophic fish species and specimen instead of high selective pressure on large, slow growing predatory species, could not only boost the sustainable yield substantially, but also alleviate the excessive fishing pressure on large fish and thereby restore the natural

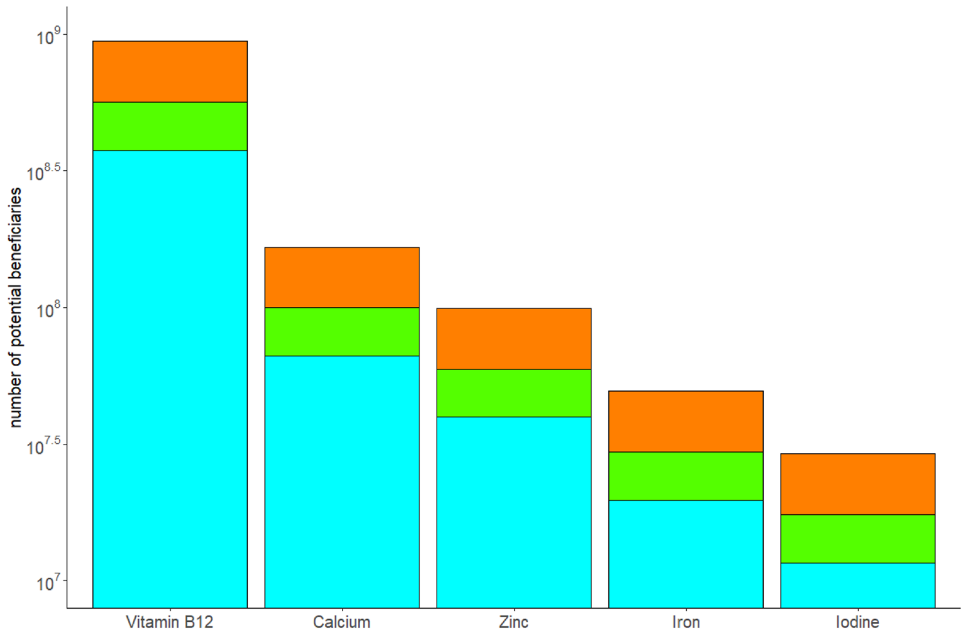

Fig. 5 Number of potential beneficiaries of sun-dried Silver cyprinid. Overlaying bars showing the number of people with nutritional needs of women in reproductive age that could potentially benefit from daily consumption of one portion of sun-dried whole Silver cyprinid containing a significant amount (≥ 15% of the daily recommended intake for women of reproductive age) of the respective nutrient based on a sustainable annual catch of 2 million tonnes of fresh Silver cyprinid. Only nutrients that can provide a significant amount of each nutrient with a serving of about 30 g were included in the figure. Orange bars indicate the number of beneficiaries without any post-harvest losses, green bars with 40% loss after harvest and blue bars with 60% of loss after harvest

demographic balance and composition in the fish populations (Garcia et al., 2012). Together, it could result in a triple-win: (i) more food, (ii) better nutrition, and (iii) a healthier more natural lake ecosystem (Kolding et al., 2019).

4.1 Nutritional value of sun-dried silver cyprinid

Assuming a serving size of 30 g, processed (sun-dried) Silver cyprinid would provide a significant amount (at least 15% of the daily nutritional requirement for women of reproductive age per portion (European Commission, 2011)) of calcium, zinc, iron and vitamin B12 and would be an almost significant source for iodine (14.4% of the daily requirement). If further assumed, one meal of the day consists of a 30 g portion of sun-dried Silver cyprinid, its consumption is an affordable potential source of foods to reduce the number of people with insufficient micronutrient intake, as it would provide essential micronutrients which are scarce in the staple starch-based diet. Especially, if Silver cyprinid is compared to the other two important and popular fish species in Lake Victoria, Nile perch and tilapia, which are commonly served as fillets (or not eaten whole) they would contain less calcium, zinc, iron, vitamin B12 and vitamin A per weight unit (FAO & Government of Kenya, 2018a, b). More specific consumption data is needed to improve the accuracy of micronutrient intake calculations for different groups of the population based on age or gender.

One quarter of the people in Kenya are considered undernourished (WHO, 2021) and deficiencies in calcium, zinc, iron, iodine and vitamin A are prevalent and common: The Kenya National Micronutrient Survey of 2011 states that 21% of women of reproductive age are deficient in iron, 82% are deficient in zinc and 35% are deficient in vitamin B12 (Kenya Ministry of Health, 2011). Furthermore, 13% of preschool children are deficient in iron and 83% are deficient in zinc (Kenya Ministry of Health, 2011). In view of these high prevalence, the calculations on micronutrient intake can be a first step to raise awareness of the potential of Silver cyprinid providing micronutrients.

The majority of the Kenyan diet consists of cereals and starchy staples with poor bioavailability of nutrients compared to animal sourced foods (Kenya Ministry of Health, 2011), which contain more bioavailable forms of e.g. iron (heme-iron) and vitamin A (retinol). Further, the "meat factor" should be considered, which is enhancing the bioavailability of iron and zinc from vegetable sourced food (Consalez et al., 2022). Small pelagic fish is the most nutrient dense animal sourced food providing calcium, vitamin B12 and substantial amounts of the fatty acids EPA and DHA (Golden et al., 2021). To reduce the prevalent deficiencies, some of these micronutrients are also part of fortification and supplement programs in eastern Africa in which starchy based staples like maize and wheat are fortified with micronutrients (Kenya Ministry of Health, n.d.). However, other measures like changes in the local diet and implementation of nutrient dense foods are recommended to also reach households who do not consume these types of industrially processed and fortified foods and reduce the prevalence of malnutrition and deficiencies (Kenya Ministry of Health; Olson et al., 2021).

Small indigenous fish eaten whole with heads and viscera has been advocated as especially rich in vitamin A (Aakre et al., 2020; Roos et al., 2002, 2003). Vitamin A, however, is one of the vitamins that is susceptible to degradation by heat and sun-light (Chittchang et al., 1999), and we have previously shown variable, and low vitamin A content in smoked whole fish samples from Ghana (Hasselberg et al., 2020) potentially caused by nutritional losses during processing. Similarly, sun-drying of Silver cyprinid enables longer non-chilled storage of the commodity, but can potentially have an impact on the quality and concentration of nutrients as well. The large variation in the concentration of vitamin A found in the samples in this study could be due to processing (Chittchang et al., 1999; Roos et al., 2002, 2007). Both, the low median and the high variability of vitamin A content in processed Silver cyprinid is making this food a less reliable source of vitamin A.

4.2 Millions of people could benefit from sun-dried silver cyprinid

A sustainable maximum catch of 2 million tonnes of Silver cyprinid per year without any post-harvest losses would potentially provide more than a significant amount of vitamin B12, calcium, zinc and iron to all estimated 33 million people in the Lake Victoria basin on a daily basis. The current catch of 0.5 million tonnes Silver cyprinid per year is however not sufficient to provide a significant amount of calcium, zinc and iron to the whole estimated lakeside community on a daily basis (LVEMP, 2007). The population numbers estimated in this calculation, nonetheless, did not account for differences in micronutrient needs from life stages or gender and are solely based on the micronutrient needs of women of reproductive age. Apart of the actual catch, also postharvest losses are affecting the amount of Silver cyprinid available as food. Post-harvest losses from moulds and bacterial spoilage can affect more than 50% of the catch and thereby significantly reduce the availability of Silver cyprinid as a safe human food source (Akande & Diei-Ouadi, 2010; Kristofersson & Ibengwe, 2012). Degraded and spoiled sun-dried Silver cyprinid is instead mostly used as feed for animals like chicken or pigs (Mutua et al., 2012; Tuitoek, 1992). However, using Silver cyprinid as animal feed instead of human food is associated with a high loss (80%) in nutrients and energy from simple metabolism. A larger number of riparian population with high quality sun-dried Silver cyprinid as food could be reached by both, an upscale of fishing capacity and a reduction of post-harvest losses practices and capacity along the value chain.

4.3 Food safety

Post-harvest processing of fish is needed to expand shelf life and distribution and thereby to make nutrients available for a longer time and a wider range of consumer groups. However, improper processing and unhygienic post-processing handling may also pose health-risks to the consumer so the quality of the fish, the way of processing and handling are crucial for the quality and safety of the final product.

Contact with microorganisms and chemical contaminants might take place in the water or in the storage bins during harvesting. While microorganisms can colonize the surface as well as the intestines of the fish, chemical pollutants (e.g., heavy metals) might accumulate in the organs and fish flesh. Quality losses is usually caused by the growth of microorganisms that make the food less preferred for human consumption by altering the odour, texture and taste of the product. Processing should ideally result in prevention of further growth of microorganisms during storage periods or even reduce the bacterial counts in the final product compared to the raw material. Quick processing after catching and/or sufficient cooling until processing is needed to limit bacterial growth until processing. Small fish like Silver cyprinid is traditionally subjected to immediate sun-drying after landing, but some hazards are associated with this type of processing, particularly during the rainy seasons or when drying is taken place on the ground, as is mostly the case. If the Silver cyprinid has not been properly dried, the water content might not be low enough to supress microbial growth. Further, contamination with microorganisms, including pathogens like STEC, from the environment (e.g. dust and dirt) or animals (e.g. birds, livestock) is at high risk during processing on the open ground. Thus, the contact with the sources of contamination, like animals or dirt, while drying of the Silver cyprinid should be limited. This might be achieved by improving the processing facilities such as using elevated drying racks (Baniga et al., 2017).

Microbiological limits by the East African Standard (DEAS 826:2014) are in place and TCC and yeast and mould counts in samples from this study and other studies were found to exceed these values (Kigozi et al., 2020; Muhame et al., 2020). Also the mean moisture content in this study (14% in dried product, see 6.) was above the required 12% in dried product by the East African Standard (DEAS 826:2014). The current way of sun-drying and storage of processed Silver cyprinid seems not to sufficiently reduce the moisture and number of microorganisms or keep it at low levels. When the fish is inadequately dried before storing and transportation, growth of bacteria and moulds is likely.

Silver cyprinid is processed and consumed without removal of the intestines and enteric bacteria are part of the natural intestinal flora of fish. This can include enteropathogenic bacteria, which could cause disease in humans (David et al., 2009). These pathogenic bacteria are likely introduced into the lake from polluted wastewater or animals (Opere et al., 2022). Discharge of untreated sewage from urban areas, informal settlements, and agricultural run-off around Lake Victoria is increasing and severe (Kolding et al., 2008; Oguttu et al., 2008). When the processing methods are not able to reduce or remove pathogenic bacteria, they might still be present in the final product. However, high temperature during meal preparation can reduce bacterial counts and reduce risks for consumers. Therefore the preparation of the meal containing dried Silver cyprinid is important for final assessment of risks for consumers.

Another aspect to consider in fish food safety is the accumulation of contaminants, e.g. mercury, lead, arsenic, and cadmium. These contaminants can have various sources, including natural and anthropogenic sources (Ngure et al., 2014; Nkinda et al., 2020; Nyangababo et al., 2005). Bioaccumulation does happen during the lifetime of the fish from the aquatic environment and the feed of the fish, but is less relevant for small fast growing fish species on a low trophic level compared to large predatory fish. However, in later steps of the value chain, processed small fish might be in contact with contaminants through air, dust and equipment (Nyangababo et al., 2005). Accumulation of these contaminants could pose a risk to the health of consumers. However, a daily consumption of 30 g sun-dried Silver cyprinid and using a conservative approach using maximal analysed values for all calculation, the intake would not exceed the TWI and BMDL01 for the contaminants (i.e. arsenic, cadmium, lead, mercury).

5 Conclusion

Sun-dried Silver cyprinid can be considered an underutilized and highly nutritious animal sourced food available to the people in Lake Victoria region. One 30 gram serving of dried Silver cyprinid can provide a large fraction of the recommended daily intake for vitamin B12, the sum of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), calcium, zinc, and iron and could therefore contribute greatly to improve micronutrient status for many malnourished people. Current catches of Silver cyprinid are only one quarter of the potential sustainable catch, offering the possibility for increased supply of this highly nutritional food commodity. However, increased catches need to go along with increased quality and capacity of improved processing procedures and infrastructure to avoid or reduce present substantial post-harvest losses. The elevated numbers of microorganisms and presence of pathogenic *E.* coli in our samples strongly indicates that the hygienic effectiveness of processing and post-processing handling of Silver cyprinid must be improved. Further research is needed to fully understand sources of potentially hazardous microorganisms and chemicals and investigate spatial and seasonal variations as well as consumption pattern. Silver cyprinid is an example of an abundant affordable but underutilized and undervalued small fish species with great potential for human health and nutrition. In international and national guidelines, more emphasis should be placed on fast growing and highly productive small sized fish species in the food supply to improve food security and fight malnutrition.

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Declarations

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