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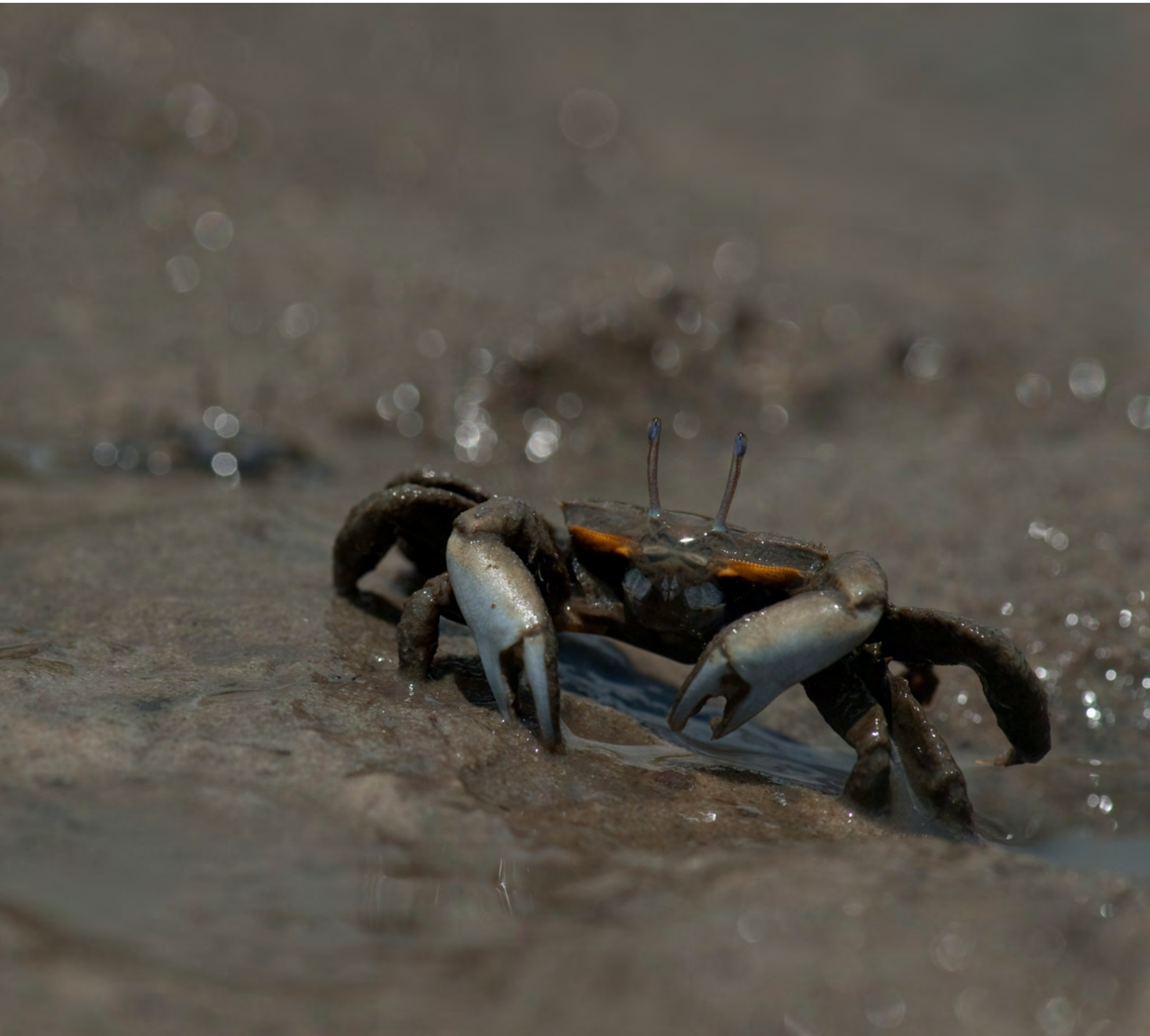

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Cover image: *Macrophthalmus depressus* at Saco da Inhaca, Mozambique (© Jose Paula, 2014)

Mineral content in local feed ingredients used by fish farmers in four different regions of Tanzania

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Abstract

This study investigated the content of selected minerals (P, Ca, K, Na, Mg, Fe and I) in local feed ingredients used by tilapia fish farmers in Tanzania. Analyses were performed on 26 local feed ingredients collected at four different geographical locations in Tanzania (Dar es Salaam, Morogoro, Mbeya and Mwanza). The samples were taken randomly from fish farmers, fish feed producers, fingerling producers and animal feed shops or centers near fish farms in each region. The results showed a wide range of mineral concentrations. The highest levels of P was found in fish skeletons (17.8 g kg^{-1}), of Ca in limestone (107.3 g kg^{-1}), of K in gallant soldier (51.0 g kg^{-1}), of Na in marine shrimp (*Exhippolysmata oplophoroides)* (11.7 g kg^{-1}), of Mg in prawn head waste (4.2 g kg^{-1}), of Fe in azolla (2355 mg kg^{-1}) and of I in full fat soybean (447 mg kg^{-1}). The data on mineral content in feed ingredients can be used as a platform for better-targeted feed formulation for tilapia farming systems. In conclusion, the data suggest that if more than two ingredients are used in the diet, this may be sufficient to meet the mineral requirements of all cultured tilapia species and their hybrids, without inclusion of any mineral premix.

Keywords: mineral requirements; feedstuffs; fish pond; aquaculture; tilapia

Introduction

In Tanzania, fish farmers raise tilapia (*Oreochromis niloticus*) in extensive systems and/or semi-intensively through fertilisation of the fish culture system (ponds and tanks) and provision of supplementary feeds (Chenyambuga *et al.,* 2014). To date, the majority of tilapia fish farmers in Tanzania feed their fish with locally available feedstuffs of both plant and animal origin. However, in order to formulate nutritionally appropriate supplementary feeds for fish, accurate data on the nutrient content of different dietary components are required. There are some limited data available (based on proximate analysis) on the major nutrient composition (*i.e.* crude protein, crude fat, crude fibre and ash) of commonly used feed ingredients in Tanzania (FAO, 1987). However, information on the mineral content of locally available feed ingredients in Tanzania is lacking.

Minerals play an important role in the maintenance of normal metabolic and physiological functions in fish and other animals, which include muscle contraction, blood clotting, enzyme activity, transmission of nerve impulses, metabolism and electrolyte balance (Tacon, 1987; Dato-Cajegas and Yakupitiyage, 1996; Assey *et al.*, 2009). Moreover, lack of essential minerals in the fish diet may lead to mineral deficiency, resulting in conditions such as anaemia, osteoporosis, stunted growth and genetic disorders (Tacon, 1987; Dato-Cajegas and Yakupitiyage, 1996; Fumio *et al.,* 2012; Bhandari and Banjara, 2015).

Iron (Fe) and iodine (I) are limited in large areas of Tanzania and deficiency of these elements causes anaemia and goitre in humans. Therefore, Fe and I were analysed in addition to the macro-minerals calcium

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(Ca), phosphorus (P), magnesium (Mg), sodium (Na) and potassium (K). In fish, Fe is involved in regulatory mechanisms controlling blood formation and respiration, hormone synthesis, fatty acid mechanism (Brody, 1994) and maintaining the integrity of the epithelium (Naser, 2000). Fish can absorb some trace minerals such as Fe not only from the diet offered, but also from their external aquatic environment through the gills (Watanabe *et al.,* 1997). The effects of limited access to I in fish are not well described, but the effects of I deficiency in fish are suggested to be similar to those in humans (NRC, 2011).

The content of Fe and I, as well as other minerals may vary in the fish diet and in the aquatic environment, therefore the aim of the present study was to investigate the mineral content of local feed ingredients used by tilapia fish farmers in Tanzania and to compare the levels measured against suggested requirements for tilapia.

Material and Methods

General

Mineral analysis was performed, according to methods described by AOAC (1990), at the food and soil science laboratories of Sokoine University of Agriculture, Tanzania. The following AOAC (1990) methods were used: Ca (968.08); P (965.17), Mg (968.08); K (956.01); Na (956.01); I (935.14); and Fe (968.08).

Samples and sample preparation

A total of 26 local feed ingredients (Table 1), collected during a field survey at four different geographical locations in Tanzania (Dar-es-Salaam, Morogoro, Mbeya and Mwanza region) (Fig. 1), were analysed for their mineral content. The samples were obtained from fish farmers, local fish feed producers, fingerling producers and animal feed centres located near fish farms in each region. In brief, 5 different local feedstuff samples (each weighing 200g) were obtained from 5 out of 20 randomly selected aqua-farmers or animal feed centres in three districts per region, depending on geographical zone, availability, specificity and climate conditions. Therefore, a total of 60 samples (15 per region) of the 26 different local feedstuffs were collected for the present study.

The collected samples of each feedstuff were pooled and sub-sampled. Briefly, the pooled sample of each feedstuff was spread out on a clean plain surface marked into quarters, and two opposite quarters were taken and mixed. This process was repeated until the two quarters selected comprised the desired amount of 100-200 g. The sub-samples were then sun-dried for 48 h, packaged and transported to the laboratory for mineral analysis. Prior to mineral analysis, samples were milled in a blender (JYL-D020 Powerful Multifunctional Blender Food Processor, Joyoung, China) and sieved by hand to pass through a sieve with 1.0mm circular openings.

For analysis of Ca, P, Mg, K, Na and Fe, 1.0 g of milled, homogenised sample was placed into a weighed porcelain crucible, which was placed in an incinerator and ignited at 450 °C until white or grey ash was obtained (Jorhem, 2000). The ash was dissolved in 10 ml of 10 % hydrochloric acid and the suspension was then filtered (No. 1 Whatman ashless filter paper, GE's Whatman Grade 40; 1440-090) prior to analysis.

For analysis of I, 2.0 g of milled sample was placed in a 25 ml Erlenmeyer flask and 10ml of deionised water was added. The mixture was shaken for 10 minutes using an orbital shaker (Baird & Tatlock, Multishaker, UK), diluted to 25 ml with deionised water and filtered (No. 1 Whatman filter paper, GE's Whatman Grade 40; 1440-090) prior to analysis.

Mineral analysis

The filtrate from both types of analysis described above was subjected to atomic absorption spectrophotometry (Atomic Absorption Spectrophotometer, UNICAM 199 AA Spectrometer, Cambridge CBI 2PX, England) for determination of Ca, Mg and Fe content, with absorbance reading at 422.7 nm for Ca, 285.2 nm for Mg, and 248.3 nm for Fe, according to the manufacturer's instructions. Standard solutions for atomic absorption spectrophotometry of each mineral were prepared by serial dilution of an appropriate stock solution. The standard solutions for Ca ($CaCl_2$) contained 0, 5.0, 10.0, 15.0 and 20.0 mg l^{-1} Ca; the standard solutions for Mg ($MgCl_2.6H_2O$) contained 0, 0.5, 1.0, 1.5 and 2.0 mg l^{-1} Mg; and the standard solutions for Fe ($FeCl_3.6H_2O$) contained 0.0, 5.0, 10, 20, and 40 mg l^{-1} Fe.

The content of K and Na in the filtrate was determined using a digital flame analyser (2655 Digital flame analyser, Chicago, USA) according to the manufacturer's instructions. Standard solutions for K and Na were prepared by serial dilution of an appropriate stock solution. The standard solution for K (KCl) contained 0.5, 2.5, 5.0 and 10.0 mg l^{-1} K and the standard solution for Na (NaCl) contained 0.5, 2.5, 5.0 and 10.0 mg l^{-1} Na. Phosphorus and I content in the filtrate was determined using an UV spectrophotometer (BIOMETE 6, WI53711, USA) with absorbance reading at 884.0 nm for P (AOAC, 1990), and at 665.6nm for I according to Narayana *et al.* (2006). The standard solutions for P (KH_2PO_4) contained 0, 0.1, 0.2, 0.4 and 0.8 ppm P and the standard solutions for I (KIO_3) contained 0, 5.0, 10.0, 15.0, 25.0 and 30.0 mg I/l.

Results

The 26 feedstuff samples analysed were classified into the following five categories: Animal by-products; Agricultural by-products; Plant leaves and weeds; Aquatic plants; and Others (Table 1). The mineral content in each sample and in the different categories are presented in Table 1 and 2, respectively.

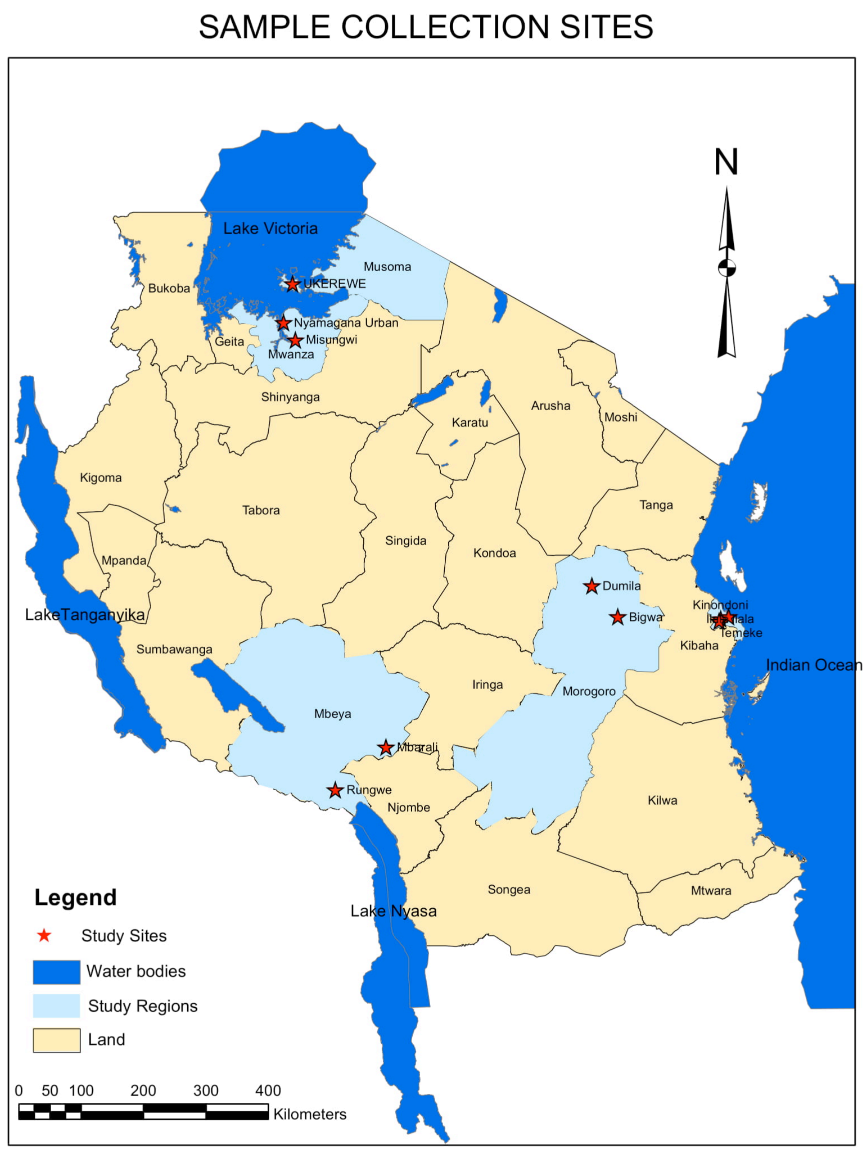

Figure 1. Map of Tanzania showing the location of the sampling sites in the four study regions: Dar es Salaam, Morogoro, Mbeya and Mwanza.

Animal by-products, except for cattle blood, had a high content of P, Ca, K, Na, Mg, Fe and I (Table 1). The mineral content in the ingredients of animal origin ranged between <0.1 and 26.6 g kg^{-1} for Ca; between 0.9 and 17.8 g kg^{-1} for P; between 2.4 and 11.7 g kg^{-1} for Na; between 94 and 370 g kg^{-1} for Fe; and between 3 and 294 mg kg^{-1} for I (Table 2).

Agricultural by-products were high in P, K, Fe and I, but low in Ca, Na and Mg (Table 1). However, one exception

Table 1. Concentration (per kg dry matter) of different minerals in local feed ingredients used by small-scale tilapia fish farmers in Tanzania.

Sample	P (g)	Ca (g)	K (g)	Na (g)	Mg (g)	Fe (mg)	I (mg)
Animal by-products							
Cattle blood	0.9	<0.1	3.2	8.5	<0.1	202	3
Fly maggot	6.6	1.4	11.1	3.6	2.2	370	167
Sardines	10.9	7.6	10.8	2.4	1.3	142	118
Marine shrimp	8.3	5.4	12.4	11.7	3.2	97	58
Freshwater shrimp	9.9	16.3	11.3	4.7	1.4	328	294
Prawn head waste	12.3	26.6	5.9	5.5	4.2	223	63
Fish frames	17.8	18.5	3.9	4.7	1.6	94	14
Agricultural by-products							
Full fat soybean	4.5	0.6	16.0	<0.1	<0.1	401	447
Soy bean	5.6	0.4	12.8	0.6	1.9	61	93
Sunflower seed cake	5.1	1.4	10.5	0.2	<0.1	146	66
Cotton seed cake	5.7	0.5	15.1	<0.1	<0.1	65	4
Maize bran	7.8	0.06	9.3	<0.1	<0.1	87	60
Rice polish	11.3	1.5	10.6	<0.1	<0.1	160	32
Wheat pollard	14.2	40.9	9.9	6.0	<0.1	78	41
Plant leaves and weeds							
Moringa leaf	3.2	8.4	14.0	0.8	3.6	95	84
Chinese vegetable	3.4	10.6	51.5	6.9	3.8	838	137
Cassava leaf	4.7	1.6	51.1	<0.1	<0.1	245	165
Taro leaf	3.2	3.2	46.5	0.1	1.6	143	89
Gallant soldier	5.6	4.9	51.0	0.2	<0.1	217	13
Sweet potatoes	0.8	0.1	7.7	<0.1	<0.1	66	15
Aquatic plants							
Azolla	5.8	1.5	31.5	5.6	1.9	2355	179
Water lettuce	4.8	13.6	33.2	4.3	0.9	229	77
Duckweed	14.3	44.8	9.3	6.7	<0.1	2265	60
Others							
Spent brewer's yeast	3.3	1.2	3.7	0.2	0.3	52	157
Seashells	0.5	93.8	0.4	3.1	2.7	320	6
Limestone	0.2	107.3	0.5	0.5	1.1	316	8

Table 2. Range of concentrations (per kg dry matter) of different minerals within the five categories of fish feedstuffs investigated.

Mineral	Animal by-products	Agricultural by-products	Plant products	Aquatic plants	Others
P (g)	0.9 - 17.8	4.5 - 14.2	0.8 - 4.7	4.8 - 14.3	0.2 - 3.3
Ca (g)	<0.1 - 26.6	0.06 - 40.9	0.1 - 10.6	1.5 - 44.8	1.2 - 107.3
K (g)	3.2 - 12.4	9.3 - 16.0	7.7 - 51.5	9.3 - 33.2	0.4 - 3.7
Na (g)	2.4 - 11.7	<0.1 - 6.0	<0.1 - 6.9	4.3 - 6.7	0.2 - 3.1
Mg (g)	<0.1 - 4.2	<0.1 - 1.9	<0.1 - 3.8	<0.1 - 1.9	0.3 - 2.7
Fe (mg)	94 - 370	61 - 401	66 - 838	229 - 2355	52 - 320
I (mg)	3 - 294	4 - 447	13 - 165	60 - 179	8 - 157

was wheat pollard, which was high in Ca and Na. The mineral content in the agricultural by-product ingredients ranged between 4.5 and 14.2 g kg^{-1} for P; between 0.06 and 40.9 g kg^{-1} for Ca; between 9.3 and 16.0 g kg^{-1} for K; between <0.1 and 6.0 g kg^{-1} for Na; between <0.1 and 1.9 g kg^{-1} for Mg; between 61 and 401 mg kg^{-1} for Fe; and between 4 and 447 mg kg^{-1} for I (Table 2).

Plant leaves and weeds showed a similar pattern as the agricultural by-products, with high values for P, K, Fe and I, and low values for Na and Mg, while the Ca content was high in wheat pollard and low in sweet potatoes (Table 1). However, moringa leaves and Chinese vegetable showed high values for Mg and Ca.

Aquatic plants were high in all minerals, except for Ca in azolla and Mg in duckweed (Table 1). In general, the Ca content was higher in aquatic plants than in agricultural by-products.

In the group 'Others', seashells and limestone showed a high content of Ca and Fe, while spent brewer's yeast showed a high I content (Table 1).

Discussion

The availability of good-quality fish feed for tilapia fish farmers is a major concern in the development of the aquaculture industry, not only in Tanzania but also across the entire East Africa region. Ideally, in addition to providing protein and fat, the feed should also supply the essential minerals needed for high performance and health. The results from the present study revealed a wide range of mineral concentrations in feed ingredients used by tilapia fish farmers in Tanzania.

The high content of P, Ca, K, Na, Mg, Fe and I in most animal by-products was in agreement with the findings of previous studies (Balogun and Akegbejo-Samsons, 1992; NRC, 1998; Chiba, 2009; Herdt *et al.,* 2000; Khan *et al.,* 2015). However, deviating results have also been reported (NRC, 2011; Odesanya *et al.,* 2011; Carter *et al.,* 2015). It should be noted that cattle blood was low in most minerals analysed, except for Na and Fe.

The mineral content in agricultural by-products (such as soybean, sunflower seed cake and maize bran) was comparable to that reported for other samples of the same feed ingredients collected in a study in Tanzania (Mutayoba *et al.,* 2011) and reviewed in a study by Chiba (2009). In general, the agricultural by-products analysed in the present study were high in K, while they had a low content of both Na and Mg. A low content of Na in local feedstuffs collected in Western Kenya has been reported previously by Onyango *et al.* (2018). Amongst the agricultural by-products analysed, wheat pollard had a high content for most minerals analysed, but in particular Ca and P.

The mineral content in plant leaves and weeds was comparable to that found in agricultural by-products in the present study. This is in agreement with previous findings (Bhanderi *et al.,* 2016; Onyango *et al.,* 2018). However, varying data have also been reported for commonly used plant leaves in fish farming and in the human diet (Dada and Owonu, 2010; Caunii *et al.,* 2010; Mutayoba *et al.,* 2011; Awol, 2014; Sun *et al.,* 2014; Temesgen *et al.,* 2016).

A very high content of Fe (>2200 mg kg^{-1} dry matter (DM)) was found in the aquatic plants azolla and duckweed. Moreover, water lettuce and duckweed showed a high content of Ca, in accordance with previous findings (Anand and Pereira 2006; Heaton, 2015).

However, varying results have been reported (Rodriquez *et al.,* 2000; Tripathi *et al.,* 2010; Wasangu *et al.,* 2013; Iram *et al.,* 2015; Adelakun *et al.,* 2016). Different growing conditions, genetic factors, geographical zone, efficiency of mineral uptake and stage of maturity can explain differences between studies (Mayer and Gotham, 1951; Bhowmik *et al.,* 2012; Izzati, 2017; Onyango *et al.,* 2018).

In general, the mineral content in spent brewery yeast, sea shells and limestone was in agreement with other studies (Chiba, 2009; NRC, 2011; Alibegović-Zečić *et al.,* 2011; Sacakli *et al.,* 2013; Amorim *et al.,* 2016; Heuzé *et al.,* 2017). Variation in mineral content between studies on seashells can be due to contamination, type and origin of shells, and for limestone on the type and form of limestone used.

Globally, variation in mineral content from one geographical area to another can be due to several factors, such as the variety of plants, stage of plant maturity, soil fertility or culture environment, soil type, mineral concentration of the soil/water, and climate conditions. In addition, processing, storage and possible contamination of samples prior to analysis may have an impact (Berger, 1996; Jumba *et al.,* 1996; Wobeto *et al.,* 2006; Steenkamp and McCrindle, 2014; Abdulkarim *et al.,* 2016; Onyango *et al.,* 2018). It is well documented that soil mineral content varies widely between different geographical zones in Tanzania, due to the presence of volcanic mountains, the Great Rift Valley and several plains and mountains with differences in elevation (Funakawa *et al.,* 2012).

In fish, some minerals can be absorbed from the surrounding water through the gills (Watanabe *et al.,* 1997). This has an impact on the mineral supply and the need for dietary minerals to meet physiological requirements (Robinson *et al.,* 1987). However, the mineral content in water can vary depending on the source (freshwater or seawater). For example, the Fe content in fresh water has been found to range between 0.06 and 44 μg l^{-1}, while that in seawater between 10 and 1400 μg l^{-1} (Terech-Majewska *et al.,* 2016).

Iodine can be absorbed by fish from the surrounding water through the gills, but freshwater fish depend more on a dietary source of I than seawater fish (Watanabe *et al.,* 1997). However, overall absorption of I in fish is determined by stress exposure, age, physiological condition and dietary supply (Terech-Majewska *et al.,* 2016). Moreover, Ca, Mg, K, Na and Fe are readily absorbed through the oral epithelia, gastro-intestinal tract, skin, fins and gills of fish (Tacon, 1987; Cooper and Burry, 2007; Kopp *et al.,* 2013; Terech-Majewska *et al.,* 2016). Absorption of minerals in fish is also dependent on the form in which these minerals are present (organic or inorganic), if they are free or bound (i.e. phytic acid, other minerals), sources (dietary or water) and route of entry (Tacon, 1987). Absorption of Ca is facilitated by dietary lactose and high gastric acidity, absorption of P in plant material is facilitated by the enzyme phytase, which hydrolyses inositol-phosphate to inositol and phosphoric acid, and absorption of inorganic P salts is facilitated by high gastric acidity (Tacon, 1987). However, absorption of Fe is depressed by high dietary intake of phosphate, calcium, phytate, copper and zinc. Moreover, absorption of Fe (non-haem iron) is enhanced by reducing substances such as vitamin C (Tacon, 1987; Terech-Majewska *et al.,* 2016).

The content of P in all feed ingredients analysed, except for limestone, met or was above the requirements of blue tilapia (Robinson *et al.,* 1987). However, for Nile tilapia the level of P supplied by sweet potato would be too low (Furuya *et al.,* 2008). Moreover, only marine shrimp, freshwater shrimp, prawn head waste, fish skeletons, maize bran, rice polish, wheat pollard and duckweed would cover the P requirements of

Table 3. Mineral requirements (per kg feed dry matter) of different tilapia species (NRC, 2011).

Species	P (g)	Ca (g)	K (g)	Na (g)	Mg (g)	Fe (mg)
Blue tilapia	0.3-0.5[1]	1.7-10[1]			0.2-0.7[6]	
Nile tilapia	2.1-7.1[2]				0.07-3.2[7]	24.7-200[4]
Red tilapia	7.6-7.9[3]					23.6-209[4]
Hybrid tilapia		0.6-10.7[4]	0.5-9.7[4]	1.5-1.6[5]	0.03-0.57[6]	

[1]Robinson *et al.,* 1987; [2]Furuya *et al.,* 2008; [3]Phromkunthong and Udom, 2008; [4]Shiau and Hsieh, 2001; [5]Shiau and Lu, 2004; [6]Lin *et al.,* 2013; [7]Dabrowska *et al.,* 1989.

red tilapia (Phromkunthong and Udom, 2008). For Ca, cattle blood, fly maggots, all agricultural products except wheat pollard, cassava leaf, sweet potato, azolla and spent brewer's yeast were all too low in Ca to meet the requirements of blue tilapia (Robinson *et al.,* 1987). All feed ingredients analysed, except seashells, would meet the K requirements of hybrid tilapia (*Oreochromis niloticus* × *O. aureus*) (Shiau and Hsieh, 2001). The Na content in all analysed animal by-products and aquatic plants in the present study met, or was above the requirements for juveniles hybrid tilapia (*Oreochromis niloticus* × *O. aureus*) (Shiau and Lu, 2004). Moreover, not only would animal by-products and aquatic plants meet the Na requirements for hybrid tilapia fish, but also chinese vegetables (plant origin) and sea shells (others). The analysed Mg content in all animal by-products (except cattle blood meal), as well as soy bean, moringa leaves, Chinese vegetables, taro leaves, azolla, water lettuce, spent brewer's yeast, seashells and limestone was sufficient to cover the Mg requirements of blue tilapia (Furuya *et al.,* 2008), Nile tilapia (Dabrowska *et al.,* 1989) and hybrid tilapia (Lin *et al.,* 2013). All feed ingredients would cover the minimum Fe requirements of Nile tilapia and red tilapia (Shiau and Hsieh, 2001). There are no established values for the I requirements in tilapia (NRC, 2011). However, the I content in all feed ingredients analysed would cover the minimum dietary level of 2.8 mg I kg^{-1} recommended for fish in general (Watanabe *et al.,* 1997). Therefore, if more than two local feed ingredients are used in the diet, this may prove sufficient to meet the mineral requirements of all cultured tilapia species and their hybrids (Table 3), without the use of any mineral premix. According to the findings from the present study, apart from animal by-products, the incorporation of wheat pollard with other ingredients such as maize bran, rice polish or other agricultural by-products to supplement the food of farmed tilapia species has proven to meet their mineral requirements for growth and health. The majority of fish farmers in Tanzania usually use maize bran and rice polish as a basic feed component in diets to tilapia. It would therefore be sufficient to add either wheat pollard, Moringa leaf or Chinese vegetables to the feed components above to ensure that the feed contains enough Mg and other minerals to meet the mineral requirement for tilapia.

Conclusions

The analyses performed in this study revealed a wide range of mineral concentrations in feed ingredients used by tilapia fish farmers in Tanzania. These novel data can be used as a platform for better-targeted feed formulation for tilapia farming systems. The data suggest that using more than two ingredients in the diet may prove sufficient to meet the mineral requirements of all cultured tilapia species and their hybrids, without the need for any mineral premix.

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References

Abdulkarim B, Bwathondi POJ, Benno BL (2016) Seasonal variations in the proximate compositions of five economically important fish species from Lake Victoria and Lake Tanganyika, Tanzania. Bayero Journal of Pure and Applied Sciences 9 (1):11-18

Adelakun KM, Kehinde AS, Amali RP, Ogundiwin DI, Omotayo OL (2016) Nutritional and phytochemical quality of some tropical aquatic plants. Poultry, Fisheries and Wildlife Sciences. pp 1-4

Alibegović-Zečić F, Piplica S, Crnkić Ć, Tahirović D, Kavazović A, Gagić A (2011) Composition of limestone for animal feeds in relation to the current national regulations. Veterinaria 60 (3-4):121-125

Amorim M, Pereira JO, Gomes D, Pereira CD, Pinheiro H, Pintado M (2016) Nutritional ingredients from spent brewer's yeast obtained by hydrolysis and selective membrane filtration integrated in a pilot process. Journal of Food Engineering 185: 42-47

Anand T, Pereira GN (2006) Azolla as a bio fertilizer in coffee plantations. Communication in Soil Science and Plant Analysis 36 (13-14): 1737-1746

AOAC (1990) Official methods of analysis of the Association of Official Analytical Chemists (Vol. 1).

Assey VD, Peterson S, Kimboka S, Ngemera D, Mgoba C, Ruhiye DM, Ndossi GD, Greiner T, Tylleskär T (2009) Tanzania national survey on iodine deficiency: impact after twelve years of salt iodation. BMC Public Health 9 (1): 319

Awol A (2014) Phytochemical screening, proximate and mineral composition of sweet potato leaves grown in Tepi Provision, South-west of Ethiopia. Science, Technology and Arts Research Journal 3 (3): 112-115

Balogun AM, Akegbejo-Samsons Y (1992) Waste yield, proximate and mineral composition of shrimp resources of Nigeria's Coastal Waters. Bioresource Technology 40 (2): 157-161

Berger LL (1996) Variation in the trace mineral content of feedstuffs. The Professional Animal Scientist 12 (1): 1-5

Bhandari S, Banjara MR (2015) Micronutrients deficiency, a hidden hunger in Nepal: Prevalence, causes, consequences and solutions. International Scholarly Research Notices 2015: 1-9

Bhanderi BM, Goswami A, Garg MR, Samanta S (2016) Study on minerals status of dairy cows and their supplementation through area specific mineral mixture in the state of Jharkhand. Journal of Animal Science and Technology 58 (1): 42

Bhowmik S, Datta BK, Saha AK (2012) Determination of mineral content and heavy metal content of some traditionally important aquatic plants of tripura, India using atomic absorption spectroscopy. Journal of Agricultural Technology 8 (4): 1467-1476

Brody T (1994) Nutritional Biochemistry. Academic Press, Inc., New York. pp 531-539

Carter NA, Dewey CE, Lukuyu B, Grace D, de Lange CF (2015) Nutrient composition and seasonal availability of local feedstuffs for pigs in western Kenya. Canadian Journal of Animal Science 95 (3): 39-406

Caunii A, Cuciureanu R, Zakar AM, Tonea E, Giuchici C (2010) Chemical composition of common leafy vegetables. Studia Universitatis" Vasile Goldis" Arad. Seria Stiintele Vietii (Life Sciences Series) 20 (2): 45

Chenyambuga SW, Mwandya A, Lamtane HA, Madalla NA (2014) Productivity and marketing of Nile tilapia (*Oreochromis niloticus*) cultured in ponds of small-scale farmers in Mvomero and Mbarali districts, Tanzania. Livestock Research for Rural Development 26 (43): 3

Chiba LI (2009) Animal nutrition handbook. Second revision. 552 pp

Cooper CA, Bury NR (2007) The gills as an important uptake route for the essential nutrient iron in freshwater rainbow trout *Oncorhynchus mykiss*. Journal of Fish Biology 71: 115-128

Dabrowska H, Gunther KD, Meyer-Burgdorff K (1989) Availability of various magnesium compounds to tilapia (*Oreochromis niloticus*). Aquaculture 76: 269-276

Dada OA, Oworu OO (2010) Mineral and nutrient leaf composition of two cassava (*Manihot esculenta* (Crantz) cultivars defoliated at varying phenological phases. Notulae Scientia Biologicae 2 (4): 44-48

Dato-Cajegas CRS, Yakupitiyage A (1996) The need for dietary mineral supplementation for Nile tilapia, *Oreochromis niloticus,* cultured in a semi-intensive system. Aquaculture 144 (1-3): 227-237

FAO (1987). Feed and feeding of fish and shrimp. Aquaculture Development and Coordination Programme ADCP/REP/87/26, United Nations Development Programme, Food and Agriculture Organization of the United Nations, Rome, Italy

Fumio K, Yasuo K, Terue K, Yoshimori K, Hideki K, Baatar P, Judger O, Ulziburen C (2012) Influence of essential trace minerals and micronutrient insufficiencies on harmful metal overload in a Mongolian patient with multiple sclerosis. Current Aging Science 5: 115-125

Funakawa S, Yoshida H, Watanabe T, Sugihara S, Kosaki T (2012) Soil fertility status and its determining factors in Tanzania. In: Hernandez Soriano MC (ed) Soil health and land use management [ISBN: 978-953-307-614-0]

Furuya WM, Fujii KM, dos Dos Santos LD, Castro Silva TS, Rosa da Silva LC, Pinseta Sales PJ (2008) Available phosphorus requirements of juvenile Nile tilapia. Revista Brasileira De Zootecnia-Brazilian. Journal of Animal Science 37: 1517-1522

Heaton W (2015) Evaluation of Blue Tilapia (*Oreochromis aureus*) for Duckweed (*Lemna minor*). Control in South Carolina's Private Waters. All Dissertations. 1598 [https://tigerprints.clemson.edu/all_dissertations/1598]

Herdt TH, Rumbeiha W, Braselton WE (2000) The use of blood analyses to evaluate mineral status in livestock. Veterinary Clinics of North America: Food Animal Practice 16 (3): 423-444

Heuzé V, Thiollet H, Tran G, Edouard N, Lessire M, Lebas F (2017) Brewers yeast. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO [https://www.feedipedia.org/node/72]

Iram S, Abrar S, Ahmad I, Khanam T, Azim A, Nadeem MA (2015) Use of duckweed Growing on sewage water as poultry feed. International Journal of Scientific and Research 5 (1): ISSN 2250-3153

Izzati M (2017) Calcium and Iron content of aquatic plants from fresh, brackish and marine water environments and their potency to be developed as soil conditioner. Advanced Science Letters 23 (7): 6455-6457

Jorhem L (2000) Determination of metals in foods by atomic absorption spectrometry after dry ashing: NMKL1 collaborative study. Journal of AOAC International 83 (5): 1204-1211

Jumba IO, Suttle NF, Wandiga SO (1996). Mineral composition of tropical forages in the Mount Elgon region in Kenya. 1. Macro-minerals. Tropical Agriculture 73 (2): 108-112

Khan ZI, Bayat A, Ahmad K, Sher M, Mukhtar MK, Hayat Z, Tufarelli V (2015) Evaluation of macro-minerals concentrations in blood of lactating and dry Desi cows. Revista MVZ Córdoba 20 (2): 4622-4628

Kopp R, Lang Š, Brabec T, Mares J (2013) Influence of physicochemical parameters of water on plasma indices in brook trout (*Salvelinus fontinalis* Mitchill) reared under conditions of intensive aquaculture. Acta Veterinaria Brno 82 (40): 367-373

Lin YH, Ku CY, Shiau SY (2013) Estimation of dietary magnesium requirements of juvenile tilapia, *Oreochromis niloticus*× *Oreochromis aureus*, reared in freshwater and seawater. Aquaculture 380: 47-51

Mayer AM, Gorham E (1951) The iron and manganese content of plants present in the natural vegetation of the English Lake District. Annals of Botany 15 (2): 247-263

Mutayoba SK, Dierenfeld E, Mercedes VA, Frances Y, Knight CD (2011) Determination of chemical composition and anti-nutritive components for Tanzanian locally available poultry feed ingredients. International Journal of Poultry Science 10 (5): 350-357

Narayana B, Pasha C, Cherian T, Mathew M (2006) Spectrophotometric method for the determination of iodate using methylene blue as a chromogenic reagent. Bulletin of the Chemical Society of Ethiopia 20 (1): 143-147

Naser MN (2000) Role of iron in Atlantic salmon (*Salmo salar*) nutrition: Requirement, bioavailability, disease resistance and immune response. PhD Thesis, Dalhousie University, Halifax, Canada

NRC (1998) Nutrient requirements for swine. National Academic Press, 10th ed, Washington, DC

NRC (2011) Nutrient requirements of fish and shrimp. National Research Council. National Academies Press, Washington DC, USA

Odesanya BO, Ajayi SO, Agbaogun BKO, Okuneye B (2011) Comparative evaluation of nutritive value of maggots. International Journal of Scientific & Engineering Research 2 (11):55-59

Onyango AA, Dickhoefer U, Rufino MC, Butterbach-Bahl K, Goopy JP (2018) Temporal and spatial variability in the nutritive value of pasture vegetation and supplement feedstuffs for domestic ruminants in Western Kenya. Asian-Australasian Journal of Animal Sciences [doi: https://doi.org/10.5713/ajas.18.0114]

Phromkunthong W, Udom U (2008) Available phosphorus requirement of sex-reversed red tilapia fed all-plant diets. Songklanakarin Journal of Science & Technology 30 (1): 7-16

Robinson EH, LaBomascus D, Brown PB, Linton T (1987) Dietary calcium and phosphorus requirements of *Oreochromis aureus* reared in calcium-free water. Aquaculture 64: 267-276

Rodríguez R, Julio C, Palma J (2000) Nutritive value of water lettuce (*Pistia stratiotes* L.) and its possibility in feeding animals. Zootecnia Tropical 18 (2):213-226

Sacakli P, Koksal BH, Ergun A, Ozsoy B (2013) Usage of brewer's yeast (*Saccharomyces cerevisiae*) as a replacement of vitamin and trace mineral premix in broiler diets. Revue de Médecine Vétérinaire 164 (1): 39-44

Shiau SY, Hsieh JF (2001) Quantifying the dietary potassium requirement of juvenile hybrid tilapia (*Oreochromis niloticus*× *O. aureus*). British Journal of Nutrition 85: 213-218

Shiau SY, Lu LS (2004). Dietary sodium requirement determined for juvenile hybrid tilapia (*Oreochromis niloticus*× *O. aureus*) reared in fresh water and seawater. British Journal of Nutrition 91 (4): 585-590

Steenkamp V, McCrindle CM (2014) Production, consumption and nutritional value of cassava (*Manihot esculenta*, Crantz) in Mozambique: An overview. Journal of Agricultural Biotechnology and Sustainable Development 6 (3): 29-38

Sun H, Mu T, Xi L, Zhang M, Chen J (2014) Sweet potato (*Ipomoea batatas* L.) leaves as nutritional and functional foods. Food Chemistry 156: 380-389

Tacon AG (1987) The nutrition and feeding of farmed fish and shrimp; a training manual 1: The essential nutrients.

Temesgen M, Retta N, Tesfaye E (2016) Effect of pre-curding on nutritional and anti-nutritional composition of taro (*Colocasia esculenta* L.) leaf. International Journal of Food Science & Nutrition 1 (1): 5-11

Terech-Majewska E, Pajdak J, Siwicki AK (2016) Water as a source of macronutrients and micronutrients for fish with special emphasis on the nutritional requirements of two fish species: the common carp (*Cyprinus carpio*) and the rainbow trout (*Oncorhynchus mykiss*). Journal of Elementology 21 (3): 947-961

Tripathi P, Kumar R, Sharma AK, Mishra A, Gupta R (2010) *Pistia stratiotes* (Jalkumbhi). Pharmacognosy Reviews 4 (8): 153-60

Wasagu RS, Lawal M, Shehu S, Alfa HH, Muhammad C (2013) Nutritive values, mineral and antioxidant properties of *Pistia stratiotes* (water lettuce). Nigerian Journal of Basic and Applied Sciences 21 (4): 253-257

Watanabe T, Kiron V, Satoh S (1997) Trace minerals in fish nutrition. Aquaculture 151 (1-4): 185-207

Wobeto C, Corrêa AD, Abreu CMPD, Santos CDD, Abreu JRD (2006) Nutrients in the cassava (*Manihot esculenta* Crantz) leaf meal at three ages of the plant. Food Science and Technology (Campinas) 26 (4): 865-869