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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
(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 (936.01); 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 (CaCl₂) contained 0, 5.0, 10.0, 15.0 and 20.0 mg l⁻¹ Ca; the standard solutions for Mg (MgCl₂.6H₂O) contained 0, 0.5, 1.0, 1.5 and 2.0 mg l⁻¹ Mg; and the standard solutions for Fe (FeCl₃.6H₂O) 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 665.6 nm for I according to Narayana et al. (2006). The standard solutions for P (KH$_2$PO$_4$) 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 l/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.

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

![Figure 1. Map of Tanzania showing the location of the sampling sites in the four study regions: Dar es Salaam, Morogoro, Mbeya and Mwanza.](image)
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 (mg) | 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      |
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). 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 (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).

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   | 0.3-0.5¹  | 1.7-10¹   |          | 0.2-0.7|        |         |
| Nile tilapia   | 2.1-7.1²  | 0.07-3.2² | 24.7-200⁴|        |        |         |
| Red tilapia    | 7.6-7.9³  | 23.6-209⁴|          |        |        |         |
| Hybrid tilapia | 0.6-10.7⁴| 0.5-9.7⁴ | 1.5-1.6¹ | 0.03-0.57|       |         |

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