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Author(s): Alexander J. Hulbert, Kerry A. Hunt and Paul E. Rose

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ABSTRACT

Turacos (Musophagidae) are common zoo birds; the 14 species of *Tauraco* being most often exhibited. Turacos possess unique non-structural, copper-based feather pigments, and a specialized dietary strategy. *Tauraco* inhabit tropical woodlands, foraging for predominantly folivorous and/or frugivorous food items. Using a study population of 16 red-crested turacos *(T. erythrolophus)* at seven zoos in the United Kingdom, the nutrient composition of diets from diet sheets was calculated, using Zootrition v.2.6, Saint Louis Zoo, USA for analyses of important nutrients within each diet, and compared against an example of currently available literature. For all nutrients analyzed, significant differences were noted between amounts presented in each zoo's diet (as fed). Turacos are presented with a wide range of ingredients in diets fed, and all zoos use domestic fruits to a large extent in captive diets. Similarities exist between zoos when comparing amounts of as-fed fiber. Analysis of the calcium to phosphorous ratio for these diets showed there to be no significant difference from the published ratio available. Whilst this is a small-scale study on only a limited number of zoos, it provides useful information on current feeding practice for a commonly-housed species of bird and highlights potential areas of deviation away from standard practice, as well as identifying ways of reducing wastage of food. Data on wild foraging behavior and food selection, or collaboration with turaco keepers from institutions in the tropics, is recommended as a way of improving feeding regimes and updating feeding practice for this and other *Tauraco* species.

INTRODUCTION

Captive avian populations are increasingly important to ensure the long-term sustainability of these taxa in zoos [Leus et al., 2011] as restrictions on the imports of wild individuals limits future sources of birds for breeding programs. An understanding of all aspects of avian husbandry, including nutrition, is vital to maintaining viable captive populations. Fundamental scientific understanding of avian nutrition comes from the disciplines of nutritional ecology, zoo biology and the poultry production industry [Dierenfeld, 1996], but extrapolation from agriculture is inappropriate for every zoo-housed taxa maintained. Consequently, research must be conducted into the specific needs of individual avian species to fill gaps in husbandry knowledge that currently exist. Evidence-based research helps keepers better understand the species they are caring for and improves provision for a species within a managed environment [Melfi, 2009].

Turacos (Order Cuculiformes; Family Musophagidae) are medium-sized birds endemic to the regions of sub-Saharan Africa [Korzun et al., 2003]. With the exception of Bannerman's turaco (*Tauraco bannermani*) (endangered), Ruspoli's turaco (*T. ruspolii*) (vulnerable) and Fischer's turaco *(T. fischeri)* (Near Threatened) the Musophagidae family are classified as least concern by the IUCN [BirdLife International, 2012b; BirdLife International, 2012c; BirdLife International, 2013]. Turacos are widely kept in captivity, as their bright plumage makes an attractive, engaging exhibit. However, due to the complexities of identifying their wild diets, information about specific nutritional requirements is limited. Turacos are predominantly arboreal and many species can be found in wooded or forested areas [Davis, 2012]. Turacos consume a primarily frugivourous diet of fruits, leaf buds and flowers [Sun and Moermond, 1997], foraging in the canopy and sub-canopy layer [Borghesio and Kariuki Ndang'ang'a, 2003; Holland, 2007].

Musophagidae have unique aspects to their plumage pigmentation. Turaco feathers contain the pigments turacin, which gives them a vibrant red color, and turacoverdin, which is bright green [Hill, 2010]. Turacin and turacoverdin are both copper-based pigments requiring ingestion of copper from the environment to be metabolized in the body. As they are frugivorous, turacos are able to extract the copper from their food item choices. It is estimated that three months' worth of fruit intake contribute to the production of newly-grown plumage [Badyaev, 2006]. It is unknown whether the natural diets of turacos are especially rich in copper but we can surmise that this may be the case as their distribution across Africa corresponds geographically with one of the world's richest copper belts [Tudge, 2010]. Copper intake should be considered when formulating a diet as although turacos appear monomorphic with both sexes sharing the same feather coloration this could be from a human perspective only. McGraw [2006] and Hill [2010] suggest that turacos may use their coloration for sexual or social advertisement, however as there have been no spectrophotometric or biochemical studies to test for differences in coloration between the sexes this remains unclear.

The difficulties of providing a complete replicate of a wild diet can be overcome by providing the correct levels of nutrients in substitute feeds instead. But only so long as these correct nutrient levels are known. Adding to such difficulty is the fact that some feeds, such as as fruits which are often considered similar to purported wild feed items can vary considerably in nutrients due to their domestic origins. Therefore, it is vital to understand the nutritional content of foods provided to specialized feeders in captivity to ensure that functional replicates within diets are exactly that.

The subject of this research, the red-crested turaco (*T. erythrolophus*) is a widely kept species in both private and public collections; whilst not endangered has a decreasing wild population trend [BirdLife International, 2012a] and hence is listed on the Convention on the International Trades in Endangered Species (CITES) Appendix II [CITES, 2016]. The sustainability of the captive population is monitored within the European Association of Zoos and Aquaria (EAZA) using a European Studbook (ESB) [ITS, 2016]. An ESB contains information about every individual registered in Europe including birth, death and parentage allowing decisions about the most appropriate pairings to be made [Glatston, 1986; Glatston, 2001]. Therefore, the success of the ESB relies on healthy individuals who are able to contribute the gene pool and hence such health status can be improved, or kept optimum, by the provision of good husbandry and welfare.

As very little research is available on the diets of Musophagidae, dietary surveys have a useful role in advancing this aspect of avian husbandry [Fidgett and Gardner, 2014]. Issues such as sugar type and concentration within fruits have not been extensively researched [Wilson and Downs, 2011a] but would appear important considerations for species such as the one focused on here. EAZA best practice guidelines suggest a wide variety of feed items for red crested turaco, however there is not any suggestion of portion size. The focus of this study is to consolidate and highlight differences in diets from several different collections and illustrate how diets provided can vary for one species. We hope to create a better understanding of the nutritional composition of diets provided to captive red-crested turaco.

METHODS

After discussion with the studbook keeper, 20 collections housing red-crested turaco within Europe were contacted for data collection. Participating collections were asked to share information on the number of animals housed and provided details of the diets provided to the animals. The questionnaire enquired about the number of birds housed and the diets provided to them. Specific information about the type of feed provided as well as weighs of food items was requested. Many of the collections replied with a photocopy of a diet sheet. All of the collections provided contact information should any further information be needed.

For the red crested turaco, the new best practice guidelines [2014] state a list of suggested fruits and vegetables but no recommended diet is given as *"not enough is known to be able to put together an officially recommended diet"*. Therefore, the diet used as the baseline for comparison in this research is this suggested list provided in the 2007 red-crested turaco published guidelines [Peat, 2007] purely to illustrate whether or not zoos are following published information when constructing diets for turacos.

Seven institutions provided information for the research: Cotswold Wildlife Park and Gardens (CWP), Paultons Family Theme Park (PP), Dudley Zoological Gardens (DZG), Exmoor Zoo (EZ), Brent Lodge (BL), WWT Slimbridge Wetland Centre (SL) and Blackpool Zoo (BP). At the time of data collection some of the zoos involved had pairs with chicks, therefore some of the diets may vary from those provided to a single pair of turaco. In total the collections provided diets for seven groups of turaco totaling 16 individual animals, detailed in the following list. CWP: 1.1.1; PP: 1.1.1; DZG: 1.1.0; EZ: 1.1.0; BL: 1.1.0; SL: 1.1.0; BP: 1.1.0 (where population number refers to male.female.juvenile).

Diets were evaluated using Zootrition®; important nutrients contained within each diet that were focused were ash, water content, crude protein (CP), crude fat (CF), acid-detergent fiber (ADF), neutral detergent fiber (NDF) and a range of important elements including calcium, phosphorous, iron and copper. The range of ingredients provided to the turacos in this study is given by Figure 1. Zoos that fed live food indicated that this was irregularly scatter-fed for enrichment.

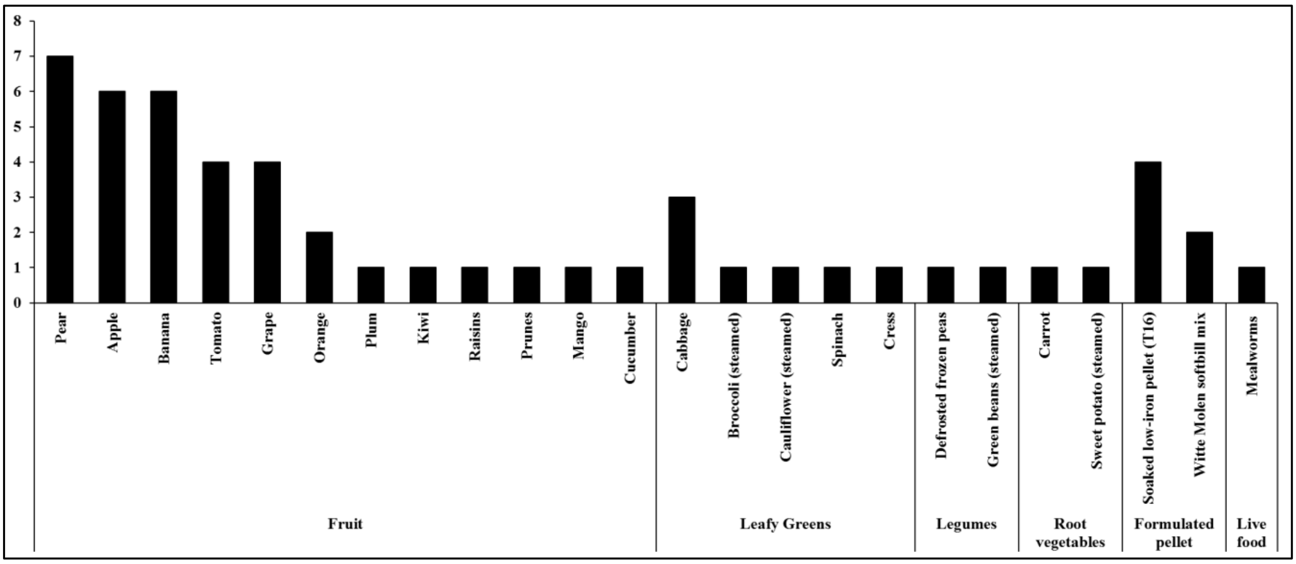

Fig.1. Ingredients listed in the diets of turacos sampled based on the number of zoos that fed each ingredient.

Analyses were conducted in Minitab v.17 and a comparison made against the published diet available in the 2007 husbandry guidelines, which was considered as an example to those keeping this species, and as a tool that zoos may use to formulate a diet for their birds. For parametric data, a one-sample t-test was used to analyze any significant difference between amount of a specific nutrient fed and that available in published literature (as a % to compare directly with the published diet), as well as analyzing differences in proportions of fruit fed between zoos and the published literature. A two-sample t-test was used to assess differences in proportions of ingredients fed. For non-parametric data a one-sample Wilcoxon test was used. For samples where zoos did differ from published information, a one-sample proportions test was used to determine how many of the zoo diets contained different amounts of a specific nutrient. One-factor Chi-squared tests were used to compare within each as-fed nutrient in the diet presented by each zoo to determine any significant differences between amounts of specific nutrients available for consumption by the birds. One-factor Chi-squared was also used to test for any difference in total amount of ingredients fed per bird per zoo.

RESULTS

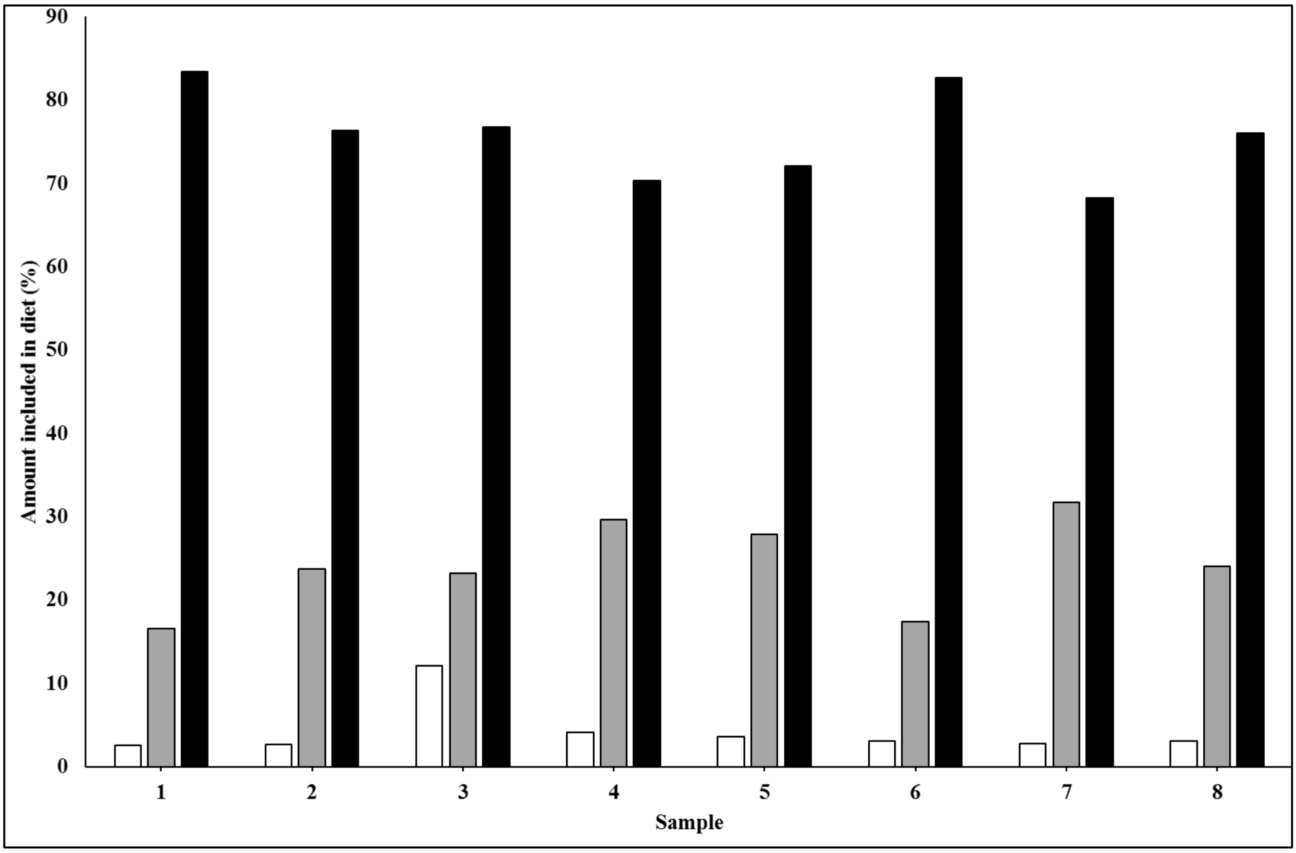

Fig. 2. Ash (white), dry matter (grey) and water (black) content of each zoo's diet, and for published information in the 2007 guidelines (number 8).

Similarities in amounts of dry matter and water with each diet provided were evident (Figure 2). However, ash, representing overall mineral and inorganic content, varied significantly for each diet (Table 3).

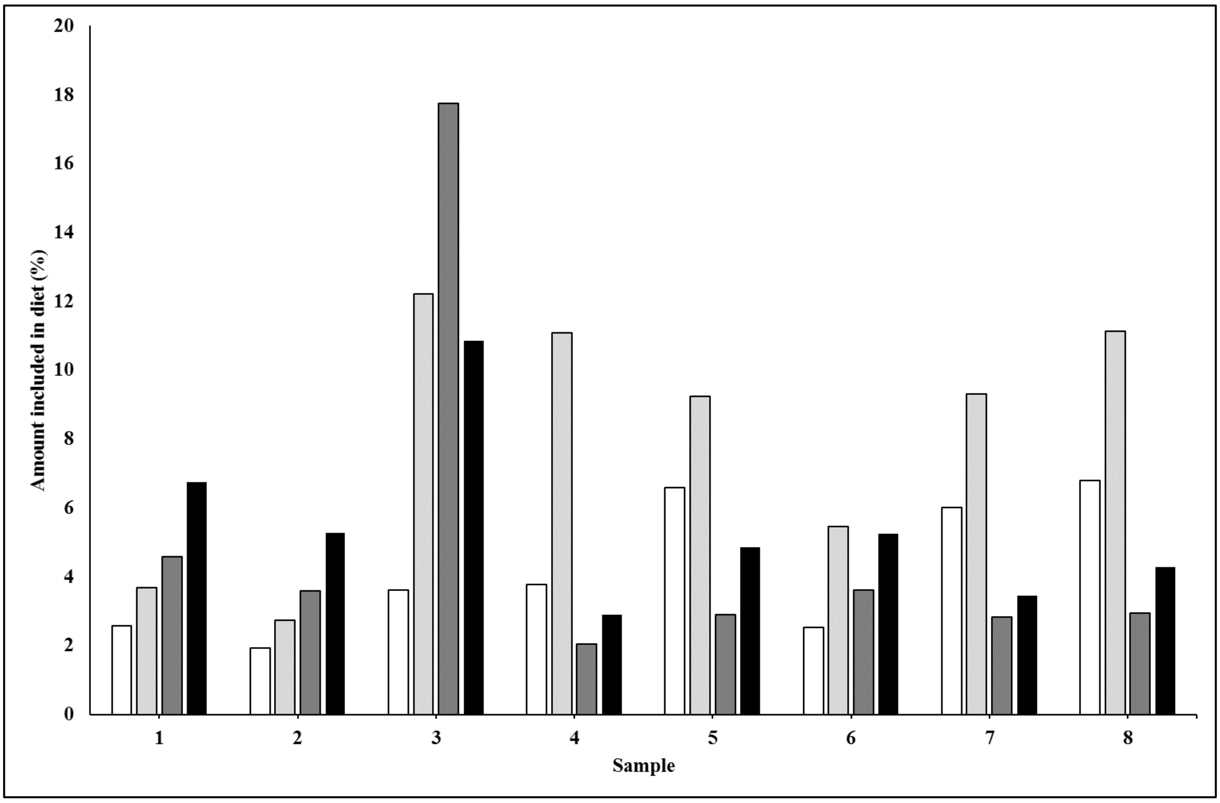

Fig. 3. Amount of Crude Fat (white), Crude Protein (light grey), Acid-detergent Fiber (dark grey) and Neutral-detergent Fiber (black) in each zoo's diet, and for published diet in 2007 guidelines (number 8).

Significant differences existed between zoos sampled for the nutritional components detailed in Figure 3, thus supporting data presented in Table 3. Differences in ADF appeared especially marked and suggest variation in the amount of roughage provided to these turacos, as well as potential differences in the digestibility of each diet and therefore the amount of energy birds can assimilate.

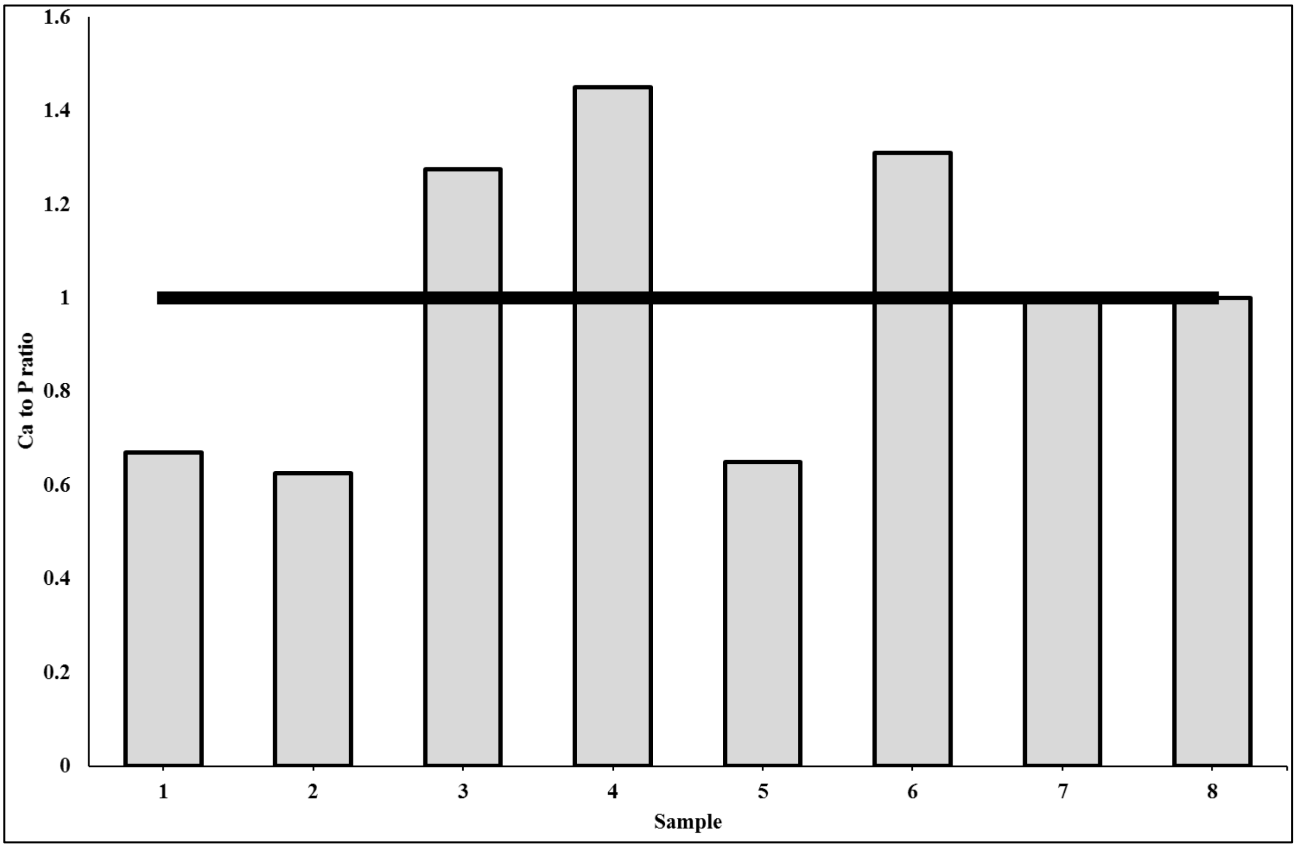

Fig. 4. Calcium to phosphorous ratio for each diet sampled, compared to published diet in 2007 guidelines (sample 8). The black line represents one unit of phosphorous. The bars represent the proportion of calcium compared to one unit of phosphorous. Three diets have a low Ca to P ratio from this calculation.

There were no differences between the Ca to P ratio of fed by each zoo and that stated in the published diet ($t= -0.02$, $P= 0.984$). When comparing between institutions, a wide variety of (as-fed) micronutrient amounts were present in the diets offered (Tables 1 and 2).

TABLE 1. Zootrition analysis of micronutrients for each sample diet (data as mg/kg) from each zoo

	Ca	P	Cu	Fe	Mg	K	Na	Zn	Mn
1	562.5	872.3	4.96	17.4	637.5	12000	200	5.48	5.11
2	498.7	821.9	20.46	32.2	650.9	16300	1000	9.32	12.02
3	5092	3974.7	82.58	150.7	1364.2	19020.7	4429.9	49.8	120.3
4	5526.6	3840.2	7.73	55.6	1177.4	5100	1199.8	60.5	51.4
5	1300	2100	3.93	18.6	500	9100	2700	4.2	500
6	1732.6	1347.4	5.16	29.8	873.1	12259.9	338.7	12.4	10.4
7	2500	2500	4.2	25.2	500	3800	2300	24.2	18.9
8	800	800	3.15	15.2	385.2	7200	2800	5.66	4.99

TABLE 2. Analysis of differences between amounts of nutrients provided to turaco (diet as fed out) at these collections. Significant P values are indicated by *

Nutrient	**Statistical output**
Calcium	χ^2= 12463.9; df= 7; P< 0.001*
Phosphorous	χ^2= 5936.36; df= 7; P< 0.001*
Copper	χ^2= 315.26; df= 7; P< 0.001*
Iron	χ^2= 333.99; df= 7; P< 0.001*
Magnesium	χ^2= 1122.95; df= 7; P< 0.001*
Potassium	χ^2= 18722.6; df= 7; P< 0.001*
Sodium	χ^2= 7820.6; df= 7; P< 0.001*
Zinc	χ^2= 157.13; df= 7; P< 0.001*
Manganese	χ^2= 2239.04; df= 7; P< 0.001*
Acid-detergent Fiber	χ^2= 756.97; df= 7; P< 0.001*
Neutral-detergent Fiber	χ^2= 78.92; df= 7; P< 0.001*
Crude Fat	χ^2= 63.23; df= 7; P< 0.001*
Crude Protein	χ^2= 11463; df= 7; P< 0.001*
Ash	χ^2= 171002; df= 7; P< 0.001*

Each institution's diet (as fed) differed in the amount of minerals presented to these turacos (Table 2). Variation was also seen in the overall amounts of fat, fiber and protein in each diet. Differences in i) make of pelleted feed provided, ii) supplement quality and amount given, and iii) amount and type of green foods and fruit provided, may account for such between-institution variation. The wide-range of ingredients used by the zoos sampled (Figure 1) emphasized why such differences would occur.

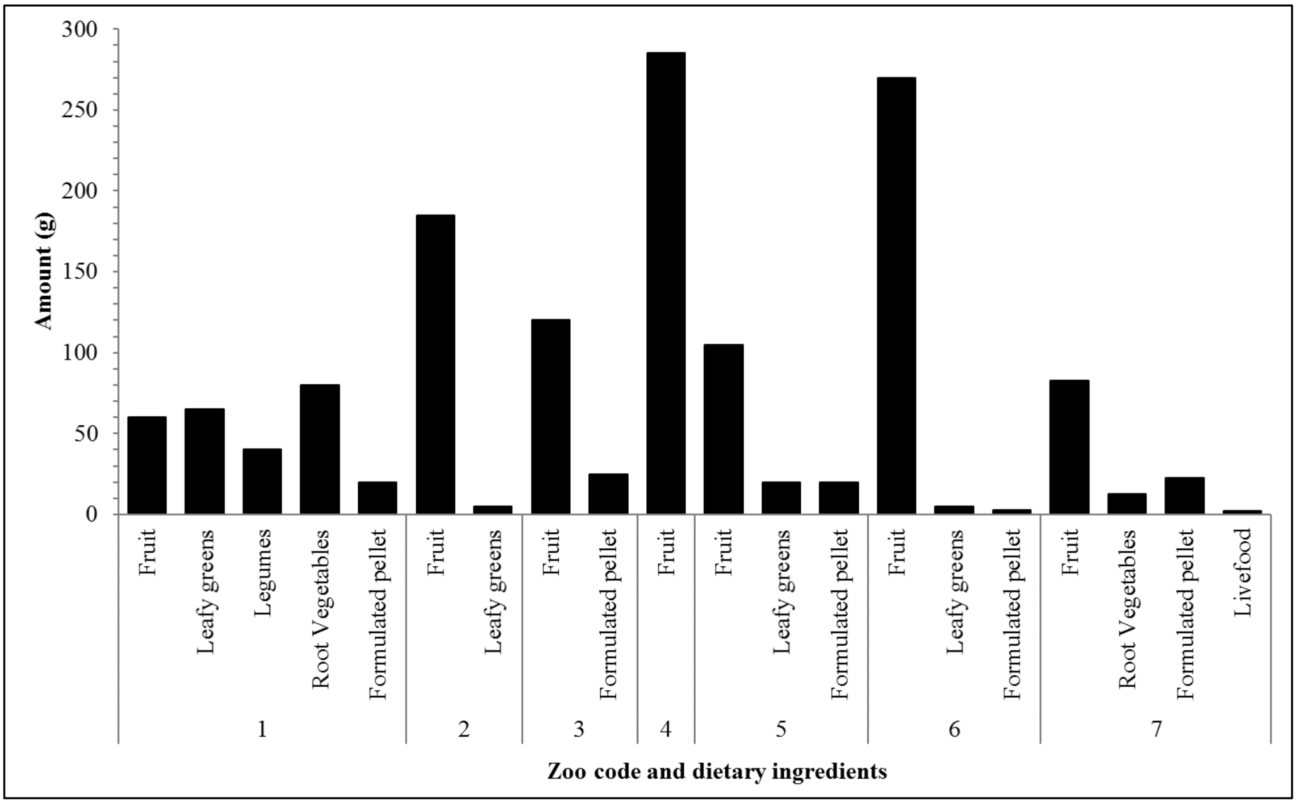

Fig. 5. Comparison of total amount of food groups (fruit, leafy greens, legumes, root vegetables, formulated pellet, live food) provided in the turaco's daily diet at each zoo sampled.

Comparing the amount of ingredients grouped into six basic categories (Figure 5) showed that all zoos sampled feed fruit in the birds' diets, but amount of fruit provided overall per bird per zoo varied considerably ($\chi 2= 309.45$; df= 6; $P< 0.001$). Interestingly, one zoo only feeds fruit whereas the majority of these collections used formulated pellet (five out seven) as part of the turaco's daily diet.

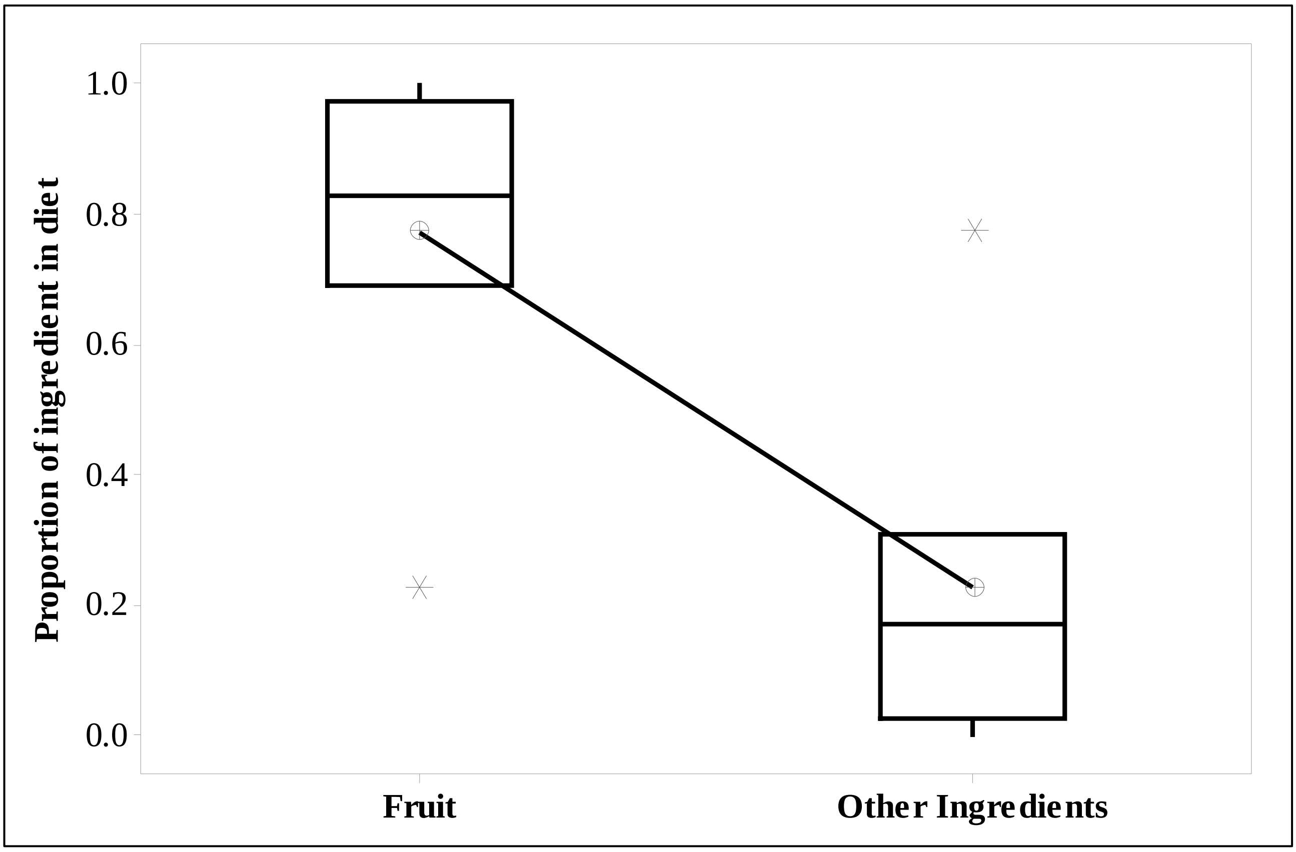

Fig. 6. Proportion of fruit in each zoo's diet compared to the amount of other, non-fruit, ingredient fed. Outliers indicated by asterisks.

Comparing the fruit and non-fruit proportions of each zoo's total diet (Figure 6) showed a significant difference in dietary make-up; the proportion of the diet consisting of non-fruit items was significantly lower for all zoos sampled (t= 3.77; df= 12; P= 0.003).

Comparing practice with published information

TABLE 3. Comparison of selected nutrients provided in sample diets compared to amount detailed in published diet. Significant P values are indicted by *

Nutrient	**Mean amount from zoos sampled (mg/kg)**	**Analysis of published diet (mg/kg)**	**Statistical output**
Calcium	2459	800	t= 2.13; P= 0.077
Phosphorus	2208	800	t= 2.82; P= 0.03*
Copper	18.4	3.15	W= 28; P= 0.02*
Iron	47.1	15.23	W= 28; P= 0.022*
Magnesium	815	385.2	t= 3.2; P= 0.019*
Potassium	11083	7200	t= 1.85; P= 0.114
Sodium	1738	2800	t= -1.88; P= 0.109
Zinc	23.71	5.66	t= 2.11; P= 0.08
Manganese	102.6	4.99	W= 28; P= 0.022*
Acid-detergent Fiber	91521	29158	W= 20; P= 0.353
Neutral-detergent Fiber	56560	42453.1	t= 1.35; P= 0.227
Crude Fat	38608	68000	t= -4.35; P= 0.005*
Crude Protein	76788	111200	t= -2.45; P=0.05*
Ash	44444	3074.9	W =14.0; P= 0.529

t = output from two-sample t-test / W= output from Wilcoxon test

There were significant differences between the amounts offered by these zoos and the 2007 published diet for phosphorous, copper, iron, magnesium, manganese, crude fat and crude protein (Table 3). The value for crude protein sits on exactly on the critical limit for significance, so it is likely this result may differ if a larger number of zoos were to be sampled.

As all zoos sampled used fruit in their turaco diet, assessing the proportion of fruit fed in these diets, compared to the proportion available in the literature showed that whilst there were differences in proportions between zoos, these were not significantly different from the amount available for zoos to follow in the published literature ($t= 0.42$; $P= 0.687$), Figure 7.

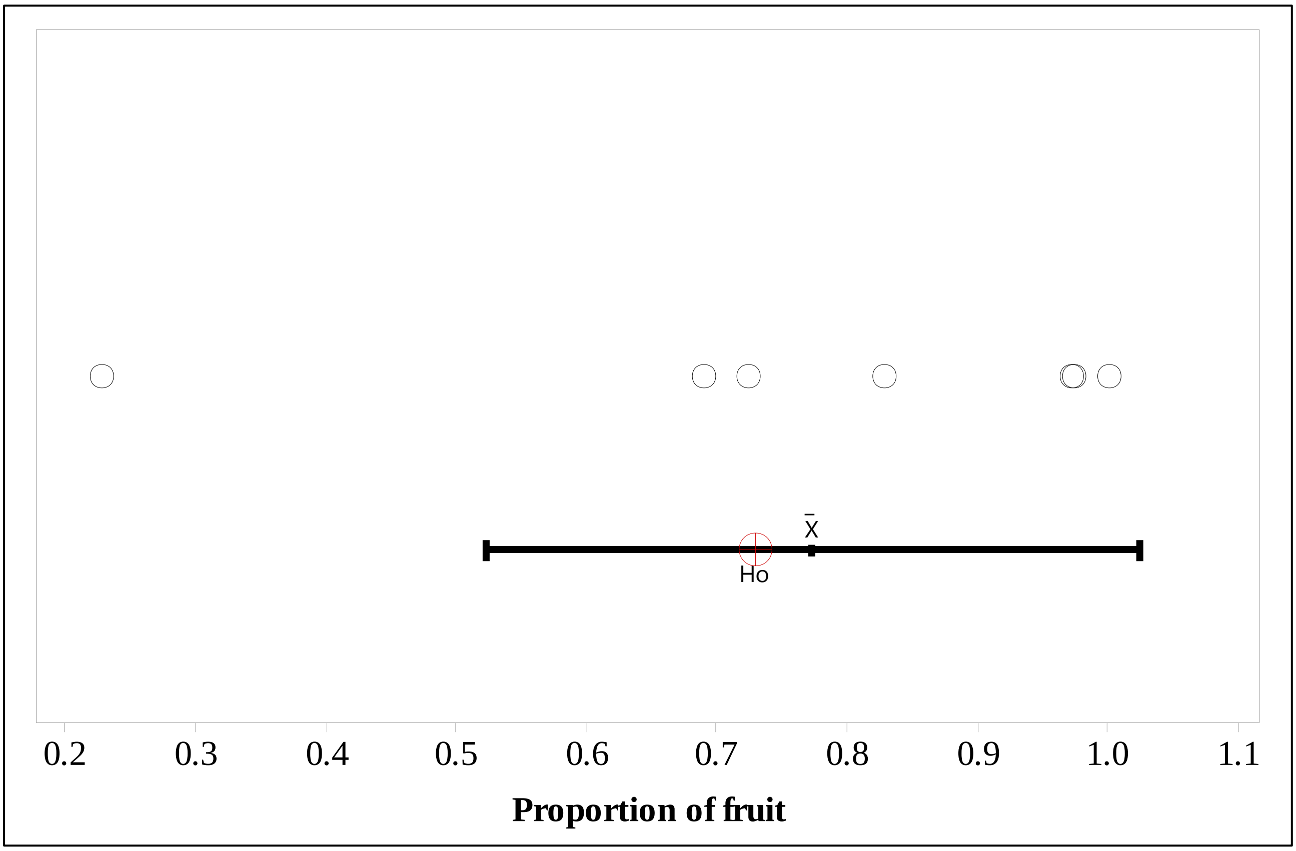

Fig. 7. Proportion of fruit within each diet sampled compared to published value (Ho) and mean from all samples (X).

DISCUSSION

This research has demonstrated whilst there are differences between zoos in amounts of nutrients presented to captive red-crested turacos in diets as-fed, there are also areas of standard practice between institutions too. Similar fiber amounts (Table 3) and calcium to phosphorous ratios (Figure 4) show that the feeding of some important nutrients can follow amounts presented in available literature. Given that turacos can suffer from metabolic bone disease as juveniles, in part due to a dietary calcium deficiency [Humphreys, 2004], care should be taken to ensure that birds are not consuming a diet where the Ca:P ratio is skewed towards phosphorous.

Differences between zoos are interesting (Table 2) and suggest that zoos may not be using the same ingredients to build turaco diets, as the range of nutrients within a diet will vary based on the constituents of the diet itself. This is supported by the information presented in Figure 1 that outlines the number of different ingredients used by these seven zoos when feeding their captive turacos. Apple, pear and banana are identified as the commonest fruits fed out to these zoo-housed birds. Wild turacos have been noted to favor the consumption of wild figs [Holland, 2007] so a suitable replacement for such a fruit should be considered by zoos housing these birds.

With research focusing on the advantages and disadvantages of feeding domestic fruits to zoo animal behavior [Britt et al., 2015] and health [Plowman, 2013], it is important to note the amount of domestic fruits used in diets of the species focused on in this research (Figure 5), and the reliance that zoos place on domestic fruit as a key ingredient for turaco diets (Figure 6). Domestic fruit can be lower in protein, minerals and vitamins than seen in wild fruits [Schwitzer et al., 2009] and as such may not always be the best substitutes for specialized frugivorous species when housed in captivity. Turacos can alter intake based on sugar content of feed [Wilson and Downs, 2011a] and hence may select for specific sugar and calorific content at specific times of the year. Further investigation into wild feeding ecology of turaco, and feed selection, which can be analyzed and used as a baseline to guide zoo diet formulation is therefore needed. However, there are positive animal welfare benefits to the feeding of diets that contain large amounts of fruits and green stuffs, as such dietary items promote natural feeding methods and foraging activity patterns thus helping to reduce the likelihood of stereotypy performance [Swaisgood and Shepherdson, 2005]. Turacos have a wide gape and can swallow fruit whole [Holland, 2007], so the provision of (appropriately selected) fruit can stimulate a natural feeding pattern. A logical extension of this research could be to calculate energy budgets of captive turaco in relation to feeding practices and determine which style of diet or feeding promotes the most naturalist behavior pattern.

The importance of dietary fiber to the health and welfare of turacos again needs further investigation. Comparatively large variance within the ADF samples (Figure 3) suggests that care should be taken with the interpretation of this result and hence further research into fiber ingestion and metabolism are needed to show how birds are digesting ADF and NDF in captivity. Selection of wild fruit items that are high in simple sugars and low in compound sugars [Holland, 2007] suggests that turacos are choosy in what types of plant material they will forage for. If birds have evolved to digest a low-sugar diet, this should be provided for in zoo-housed feeding regimes, and therefore the fruit-heavy diets currently fed may be inappropriate. As amounts of fruit fed are high in all diets apart from one (Figure 7), it would be useful to assess body and feather condition of birds in these collections to determine the effect of diet on physical health. Likewise, assessment of passage time and diet digestibility would yield useful information to support the need for a best practice diet, based on ingredients that stimulate the most natural rate of passage, for wider dissemination around zoos. However, such a diet may, in part, be reliant upon collection of wild feeding ecology data that helps identify key areas of feed selection and natural amounts of wastage (Jordan, 2005) that can inform the correct types and amounts of ingredients to be used in captivity.

There are differences noted in the amount of copper present in the diet of each zoo (Table 2), as well as differences between zoos and the published dietary information (Table 3). As the specialist pigments manufactured by turacos rely on copper, and as copper can be found in elevated concentrations to achieve these specific plumage colors [Dyck, 1992], more research into the effects of varying copper levels in diets of captive turacos may be required. As noted in other species who utilize dietary pigments for plumage color, changes to feather color intensity and hue may alter the performance of important behaviors linked to mate choice and courtship [Freeman et al., 2016; Rose et al., 2014].

Research shows that diet can account for a large percentage of the expense of maintaining tropical birds in captivity [Cruz et al., 2016]; reducing costs at the same time as promoting excellent animal welfare can be achieved by correct feeding and dietary formation [Fidgett and Gardner, 2014]. Figure 7 shows that the difference in proportion of fruit fed from each zoo to the suggestion in published information is not different. So zoos are making up diets with a similar balance of fruit to non-fruit items as is suggested. However, there are significant differences between zoos in how much fruit is provided per bird per diet (Figure 6), as well as overall amounts of different ingredients used to create diets (Figure 5) suggesting there are areas for standardization of practice to improve diets and reduce use of excess ingredients.

Standardized ways of feeding zoo animals ultimately benefit those caring for the species as well as the animals themselves [Fidgett, 2005] by making correct, valid information more easily accessible. Regular reviews of diets, and the use of research projects to update and advance feeding guidelines help zoos meet their conservation and captive breeding goals [Fidgett and Gardner, 2014] and ultimately advance the way in which a species is managed in a biologically-relevant fashion.

As this project only measured diets as fed and did not attempt to quantify availability of nutrients or digestibility, it simply presents results to demonstrate potential similarities or differences between zoos in dietary make-up. Further study should expand upon measurement of digestibility in individual captive turacos to ascertain which diets provide the most available energy and which are therefore being processed most effectively by the birds themselves. It must be acknowledged that there are limitations to the methods used, notably the use of computer software for assessment of nutritional content as opposed to proximate analysis in the laboratory. The small number of turaco diets included in this study, and no measurement of seasonality of nutrient content of feeds provided over the long term means a conservative approach to these results is needed.

Further, detailed assessment of nutritional content and quality of these turaco diets, as well as comparison between individual birds, populations and institutions, would be possible if total excreta were measured. Studies on digestibility in other avian species [Foeken et al., 2008; Kalmar et al., 2007] have been successfully performed via collection of fecal matter, thus providing a more reliable indication of how nutrients are being metabolized by the bird they are provided to. Given that turacos are generally kept in large, planted, mixed aviaries, it may be different to perform such an experiment without removing the birds to a more controlled environment.

Collaboration with turaco keepers from tropical zoos, alongside of wild data on foraging behaviors and food selection, is recommended as a way of updating feeding practice for this, and other, *Tauraco* species. Research on related species *(T. corythaix & T. porphyreolophus)* shows the effect of fruit (sugar) type on turaco gut transit time, food selection and energetic demand [Wilson and Downs, 2011a; Wilson and Downs, 2011b], opening up more avenues for future research into captive food provision for Musophagidae. Red-crested turacos have morphological similarities with an allopatric species, Bannerman's turaco [Njabo and Sorenson, 2009]; therefore, data collection on one species may also be useful to advancing knowledge of the husbandry requirements of others.

Best practice guidelines published by EAZA summarize the situation with the feeding of this species nicely; red-crested turacos are kept by a range of collections but little is known about their wild ecology [Peat, 2014]. As such, data to evidence the formulation of the "best", most appropriate diet is currently lacking. By comparing how diets can follow published information (Table 3) and by comparing between zoos to show the range of food items provided (Figures 2 and 3), and by illustrating the popularity of specific ingredients compared to others (Figure 1), we have identified common trends within the feeding of this species that can be built on for a future, larger dietary study.

The diet that most closely matched the guidelines provided 69% fruit, 18.8% formulated pellet, 10.5% root vegetables and the remainder in live food (diet 7). This suggests that turacos may require less food than is provided in most collections with amount of food varying from 119.5g (diet 7) to nearly 300g (diet 4); therefore, collections should review the amount of uneaten food in exhibits and alter diets to reduce wastage and save money.

CONCLUSIONS

1. Captive red-crested turacos are presented with a wide range of different ingredients in diets fed but all collection use domestic fruits to a large extent in captive diets.
2. There are significant differences between the amounts of specific nutrients within each total diet presented to turacos in each zoo, and zoos should consider reducing amount of feed provided to reduce costs and prevent unnecessary wastage.
3. There are similarities between zoos when comparing amounts of as-fed ADF and NDF, and for calcium-phosphorous ratios of diets fed too, based on an example of published literature.
4. Further research into the role fruit selection based on sugar content and suitable replacements for domestic fruits in captive diets is suggested.

5. Investigating use of copper in turacos for sexual selection and communication would be useful to determine optimal required amounts in the bird's diet to maintain plumage color and quality.
6. Future research should investigate digestibility of available diets, and selectivity of feeds by the turacos to ensure that all important available nutrients are consumed by the birds themselves, as well as use of a proximate analysis approach to determine nutritional content of total diet offered.

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