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RELATIVE ANALYSIS OF TWO CITRUS SPECIES VERSUS MAIZE FOR POTENTIAL NUTRITIVE TRAITS AS LIVESTOCK FEED

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Supporting Information

ABSTRACT: The present study seek to assess the nutritional qualities and the mineral composition of citrus fruits (pulps + peels) of two different species (*Citrus clementina* and *Citrus limon*), while comparing its nutritive perspective with *Zea mays L* (yellow maize) commonly used as livestock feed. Proximate evaluation was done via the method of the association of official analytical chemists (AOAC). Elemental components of citrus species were measured by means of a standard spectrometer. The proximate evaluation of the sample indicated that *Citrus limon* fruit contained comparable amounts of protein, fibre and lipid, but significantly higher ash contents than yellow maize. While the *Citrus clementina* was higher in protein and ash content, but comparable moisture content to *Zea mays L*. Meanwhile, minerals including Ca, Mg, K, Na, Cu, Mn and Fe were significantly higher in the two citrus species than in *Zea mays L*. Therefore the manuscript revealed that the *Citrus clementina* and *Citrus limon* species possess the potentials to be utilized as livestock feed ingredients.

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INTRODUCTION

A large chunk of food produced worldwide is wasted, causing about 1.3 billion tons of food to go into waste (Morshedy et al., 2022). Among these recorded food wastes, 45 % of them are generated from fruits and vegetables (FAO, 2016). These food wastes are known to be produced by agro-industrial processing, agricultural production, and damage during storage and transportation (Torres-Leon et al., 2018). However, information on the optimum utilization of fruit and vegetable wastes is scarce, leading to grave impacts on the immediate surroundings, economic, and social sectors (Morshedy et al., 2022). Due to this menace, different research works have been reported in an effort to assess ways of lowering food wastage, and reducing their economic and societal menace (Castro et al., 2020).

Several bioactive compounds in citrus fruits varies from one species to the other and in their different parts (Karasawa and Mohan, 2018; Maheshwari et al., 2022). For instance, citrus waste peels possess an extensive diversity of minor compounds with high antioxidant reactions in comparison to the other parts of citrus fruit (Czech et al., 2020). Peels are also fingered as a source of pectin, molasses, and limonene (Manthey and Grohmann, 2001; Rafiq et al., 2018). The rind (outer portion) of citrus fruits is often processed and used as diet for cattle (Zema et al., 2018). Meanwhile, at other times, the rind of citrus is disposed into society and treated as fruit waste, which contains 50 % of the whole weight of the fruit (Anagnostopoulou et al., 2006; Marin et al., 2007). These wastes are seen as possible source of environmental pollution (Barros et al., 2012). Peels from citrus fruit also possesses several natural compounds, such as heraclenin, auraptene, imperatorin, and bergamottin, and bio-active elements, with advanced dietary and therapeutic worth (Genovese et al., 2014; Sunagawa et al., 2022). The relatively insignificant monetary value and widely available citrus materials such as their peel and pulp, which appears to be waste of citrus, can be seen as a prospective source of animal feed and nutraceuticals (Rafiq et al., 2018; Zema et al., 2018). Whole citrus (pulps and peels) fruits, being rich in bioactive molecules can be used as dietary additives, dietary fiber, antioxidants, and mineral ingredients (Czech et al., 2020). Citrus fruits, from their various species such as lemon, limes, soft citrus, and mandarins are among the broadly grown fruits globally, due to its wide public demands. Several nations including Spain (leading in highest amount of production), Italy, Turkey, Portugal, Greece, Morocco, Tunisia, and Algeria are foremost producers of clementine fruits with an estimate of about 25 % (about 4,795,000 tons) of the whole citrus species in the regions around the Mediterranean basin (Fabroni et al., 2016). In other continent like South America, the production of Clementine citrus is projected at about 2 million tons, with nations such as Brazil, Peru, Uruguay, and Argentina taking the leading in terms of production (Fabroni et al., 2016). In the continent of Asia, China is known (contributing about 14 million tons) to be the highest producer of Clementine citrus from its overall production of 19 million tons (Fabroni et al., 2016).

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Citrus fruit, is an essential crop in South Africa (Ladaniya, 2008). About 1.6 million metric tons of fruits are reported harvested and processed in South Africa yearly. They are processed into juice drinks, leaving their peels and pulps as unwanted products and wastes. South Africa is a key exporter of citrus fruits. This invariably suggests that tons of waste are generated in the process, and are often discarded into the surrounding.

More than 50 % of citrus fruit produced in South Africa goes into waste with Eastern Cape Province leading the park (Van Dyk et al., 2013), and these wastes are regularly thrown away into the environment (Botha, 2003). Likewise, in Egypt for instance, it was reported that more than 1.9 million tons of crop wastes are discarded on a yearly basis, among which citrus fruits contribute a large proportion (Alnaimy et al., 2017). Unwanted waste generated from citrus fruit processing is a potential economic and societal nuisance if they are not effectively transformed or biodegraded for value addition/useful materials (Tripodo et al., 2004).

There is currently an increased quest for alternative feedstuffs for improving livestock farming globally. This is because of the constant rise in the regular animal feedstuffs which most animal farmers may not be able to afford. The current bulk of citrus fruits as by-products from citrus farms could be useful in bridging the feed gap in livestock farming and reducing the recurring animal-human competition on grains, especially maize. Therefore, investigating the potential of different citrus fruits as a prospective livestock feedstuff is worth the while.

According to Ülger et al. (2020), citrus wastes used as feedstuffs lowered the price of feed, thereby increased profit. Judging from this perspective, citrus fruits (labelled as wastes) are seen to be an important feed alternatives in livestock dietary scheme (Ülger et al., 2020). According to Steyn et al. (2017), citrus fruits can be harvested, processed and utilized as animal feed to boost livestock husbandry. Equally, the attempt to evaluate the nutritive prospect of citrus fruits (pulp and peels) of South African origin is calculative, as this could be an insightful venture in the right direction with respect to its use as an alternative feed to yellow maize for farmers judging from the constant hike in the price of grains including yellow maize. According to the research by Steyn et al. (2017), they observed that citrus fruit waste may be fed to livestock as sole-feed, or/and as a substitute, thus citrus fruit could form an essential in their feeding scheme. The goal of the current manuscript is therefore to assess the proximate and elemental values of whole (peel and pulp) *Citrus clementina* and *Citrus limon* fruits as a potential livestock feed resource, and to compare their nutritional parameters to that of *Zea mays L* (yellow maize), a commonly used livestock feed (chicken, goats, sheep etc.) by indigenous farmers in South Africa. The nutritive characteristics of these dried whole citrus fruits were compared to that of *Zea mays L* (yellow maize) obtained from an agro-allied store. *Citrus limon* and *Citrus clementina* fruits were adopted for this work because they are abundantly available in the study area with several commercial citrus farms located in the area.

MATERIALS AND METHOD

Procurement of yellow maize

The *Zea mays* L (yellow maize) that was used in this study was purchased from a well-known farm store precisely from the town of Alice where most indigenous and commercial livestock farmers purchase yellow maize for animal feed. Alice town is a small town in the Eastern Cape region of South Africa. The variety of the yellow maize which is a well-known grain in the area is the Okavango flint maize. The geographical location of Alice town is situated at 32° 43028.66" and 26° 3405.88" in latitude and longitude.

Citrus waste collection

The complete citrus fruit of *Citrus limon* and *Citrus clementina* fruits which were meant to be waste (since they have lost their market values in terms of appearance by the owners) were gotten from a well-known commercial citrus farm (Nandeshook farm) and kept in clean plastic bags before further processing in the laboratory. The *Citrus* fruits gotten from the farm site were Eureka Lemon and Clementine (*C. limon* and *C. clementina*), all from the Eastern Cape region of South Africa with geographical co-ordinates of -33° 44'43.04".

Sample preparation of citrus fruit (pulps + peels)

The citrus fruits of *C. clementina* and *C. limon* were cut into pieces and spread on a flat clean surfaced platform (wooden materials) for air-drying and drained of their liquid. After drying, the citrus fruits were afterward oven-dried at a temperature of 50 °C for two days (48 h) to get the desired dried matter. The samples were blended into small particles using a blending machine. The blended samplers were neatly gathered into clean plastics, labeled and kept in cool conditions, for further evaluation.

Analysis of proximal composition of citrus fruit

Determination of moisture component

The moisture constituent of the prepared citrus fruit was done via standard practice (AOAC, 2000). With the aid of a drained and empty weighing container weighed (W_i) in an oven for measurement of its initial weight. The sample was then kept in the previously measured container and then weighed for the second time (W_j), and oven-dried for three days (72 h) at 40 °C. The sample was afterward cooled and reweighed (W_k). The value of the water content was obtained using following formula:

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Moisture content (%) = $\frac{W_j - W_k}{W_j - W_i} \times 100$

Where; W_i represents the weight of the empty container; W_j represents the weight of the container + drained citrus fruit before drying; W_k represents the weight of container + drained citrus fruit sample.

Ash content determination

The content of ash in the drained citrus fruit was determined via the procedure of the dry ashing method (Agrilasa, 2007). The container was dried at 105ºC for one hour, thereafter the container was weighed on cooling (W_i). Following that, 2 g of the samples were kept in the weighed vessel and re-weighed (W_j). The container, together with the sample was then ashed at 250 ºC for an hour. The ashed samples were then left to cool down and later weighed again (W_k). The citrus ash was evaluated as follows:

Ash content (%) = $\frac{W_j - W_k}{W_j - W_i} \times 100$

Where; W_i is referred to the weight of the dried container; W_j is referred to the weight of container + whole *Citrus* fruit (pulps + peels) sample; W_k is the weight of container + ashed *Citrus* fruit (pulps + peels) sample.

Crude protein

Crude protein was estimated from the total nitrogen (TN) constituent in the sample using the micro Kjeldahl technique (Hussain et al., 2011).

Percentage nitrogen content (%) =

$$\frac{[(\text{mL standard acid} \times \text{N of acid}) - (\text{mL blank} \times \text{N of base})] - (\text{mL std base} \times \text{N of base}) \times 1.4007}{\text{Weight of sample (g)}}$$

Where; N represents the normality i.e. 1.4007 known as the single factor of nitrogen molecular weight;

Calculation of Crude protein = Nitrogen content (sample) × 6.25

Crude fibre determination

Dietary fibre of sample was determined using the technique of the modified acid-base digestion procedure (Aina et al., 2012). The crude fibre was calculated below as;

Crude fibre (%) = $\frac{C_2 - C_1}{\text{Weight of Sample}} \times 100$

Where; C_1 = is referred to the weight of container + whole Citrus fruit (pulps + peels) sample; C_2 is the weight of container + ashed Citrus fruit (pulps + peels) sample.

Crude Lipid determination

This was determined using the Soxhlet extraction method (Al-Harrasi et al., 2012). The estimation of lipid was determined using the formula:

Crude lipid (%) = $\frac{W_2 - W_1}{\text{Weight of original sample}} \times 100$

Where; W_1 is referred to the weight of container + whole Citrus fruit (pulps + peels) sample; W_2 is the weight of container + ashed Citrus fruit (pulps + peels) sample.

Determination of total carbohydrate content

This was done by deducting crude fibre, total protein, ash content, crude fibre, and lipid from the total dry matter of the sample: Total carbohydrate (%) = 100 − (crude fibre + % moisture content + total ash + crude protein + crude lipid).

Determination of energy value

The aggregate of energy value of citrus fruit was determined using the Atwater factors as follows: 4 kcal, 9 kcal, and 4 kcal to determine the caloric figure. The sum of the multiplied lipid, crude protein, and carbohydrate, is explained from the formula below:

Energy value (kcal/100 g) = (total carbohydrate × 4) + (crude fat × 9) + (crude protein × 4) (Idamokoro et al., 2022).

Mineral determination

The mineral evaluation was done to quantitatively analyze mineral attributes in the citrus fruit (pulps + peels) segments. The elements that were determined including iron, manganese, phosphorus, potassium, copper, calcium, magnesium, sodium, nitrogen and zinc were analyzed via the Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

Sample preparation of yellow maize

The purchased yellow maize was crushed into fine particles using a blending machine. The blended citrus fruits were neatly assembled into clean plastics, labeled, and kept in cool conditions, before carrying out further analysis. The same

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procedure that was used for analysing the elemental and proximate composition of the citrus fruits, was also employed to analyse the yellow maize. The yellow maize and the whole citrus were analysed in triplicates.

Data analysis

Analysed citrus fruit and yellow maize samples were given as mean ± standard deviation before being estimated in a one-way analysis of variance (ANOVA) using the MINITAB 19 statistical software. ANOVA was pegged at 95 % using the Fisher LSD confidence level. The measurement of statistical differences was placed at a probability of $p < 0.05$.

RESULTS

Nutritional component

The proximate contents of citrus from *Citrus limon* Pulp + Peel (CLPP); and *Citrus clementina* Pulp + Peel (CCPP) gotten from the commercial farm representing the nutritive contents of their pulps + peels and *yellow maize* are shown in Table 1.

The moisture content (MC) values of the citrus CLPP and CCPP were given as 11.87±0.41 % and 9.71±0.60 %, respectively, while it was 9.22 ±0.12 % in yellow maize. Of the three samples, highest content of ash was recorded in CLPP (5.91 ± 0.27 %) significantly, followed by CCPP (5.08±0.03 %) and yellow maize (1.47±0.04 %).

The content of lipid was highest in CLPP (4.27±0.02 %), which was statistically at par with maize (4.13±0.17%), but was significantly higher than those of the CCPP (2.92±0.12 %). The crude fibre content for yellow maize (30.66±3.36 %) had comparable mean value to the CCLP (27.63±3.23 %), but had significantly higher mean value CCPP (19.67± 0.36 %) accordingly. The crude protein content of CCPP fruit had a significantly higher mean value of 6.65± 0.20 % compared to maize (5.06±0.10 %), and CLPP (4.92±0.06 %). Total carbohydrate content mean value for yellow maize (68.24±4.49 %) was significantly higher compared to those of the CLPP fruit (4.84±0.93 %) and CCPP (3.13± 0.35 %). The aggregate energy mean value for yellow maize was 330.39±16.26 % which was significantly higher than those of CLPP fruit (70.72±6.60 %), and CCPP fruit (65.46±2.57 %).

Table 1 - Nutritional components (%) of *Citrus limon* and *Citrus clementina* from a commercial farm as compared to *Zea mays L*

Parameters (%)	CLPP	CCPP	*Zea mays L*
Moisture	11.87±0.41[a]	9.71±0.60[b]	9.22±0.12[b]
Ash	5.91±0.27[a]	5.08±0.03[b]	1.47±0.04[c]
Lipid (Fat)	4.27±0.02[a]	2.92±0.12[b]	4.13±0.17[a]
Carbohydrate	4.84±0.93[b]	3.13±0.35[b]	68.27±4.49[a]
Protein	4.92±0.06[b]	6.65±0.20[a]	5.06±0.10[b]
Fibre	27.63±3.23[a]	19.67±0.36[b]	30.66±3.36[a]
Caloric value	70.72±6.60[b]	65.46±2.57[b]	330.39±16.26[a]

The letter variants along a row indicates significant differences at p < 0.05 among samples of *Citrus limon, Citrus clementina* and *Zea mays L*. CLPP= Citrus Limon Pulp + Peel; CCPP = Citrus Clementina Pulp + Peel. The values of components reported are mean ± standard deviation. NB: Caloric value: (kCal/100 g). Data is based on dry matter.

Mineral Composition

The citrus fruit and maize samples showed significant variation in their mineral composition (Table 2). Calcium content was significantly higher in the CLPP (603.33±20.55 mg/100 g) than CCPP (396.67 ± 4.71 mg/100 g) with maize (10.00 ± 4.71 mg/100 g) samples. Magnesium was also significantly higher in CLPP fruit (130.00 ± 0.00 mg/100 g) than CCPP (113.33 ± 4.71 mg/100 g) and maize (100.00 ± 0.00 mg/100 g) samples. The peak value of potassium was recorded in CLPP fruit (1503.33±16.99 mg/100 g) which had a statistical difference from that CCPP fruit (1453.33±16.99 mg/100 g), and maize sample (350.00±8.16 mg/ 100 g).

The CLPP excelled statistically for sodium content (73.33 ± 4.71 mg/100 g) over CCPP (43.33 ± 4.71 mg/100 g) and maze (20.00 ± 0.00 mg/100 g) samples. Likewise, zinc mean value was also highest in the CLPP fruit (4.63 ± 4.43 mg/100 g), followed by CCPP fruit (1.70 ± 0.21 mg/100 g) and maize (0.65±0.56 mg/100g) with no significant difference. Meanwhile, maize proved best significantly for phosphorus content (233.33 ± 4.71 mg/100 g) over CLPP (173.33 ± 4.71 mg/100 g) and CCPP (156.67 ± 4.71 mg/100 g). The CLPP had significantly higher manganese content (1.00 ± 0.08 mg/100 g) followed by CCPP (0.80 ± 1.11 mg/100 g), while it was lowest in maize (0.50 ± 0.00 mg/100 g). Copper was generally low in content, being the highest in CCPP fruit (0.27 ± 0.05 mg/100 g) statistically, followed by CLPP (0.20 ± 2.77 mg/100 g); no copper was found in the maize sample. The CLPP tended to show the highest content of iron (5.23 ± 0.23 mg/100 g) significantly over CCPP (3.77 ± 0.05 mg/100 g) and maize sample (2.90 ± 0.59 mg/100 g).

The sodium-potassium ratio (Na^+/K^+) was registered significantly highest in CCPP fruit (1.29 ± 0.01 mg/100 g) when compared to maize (1.07 ± 0.02 mg/100 g) and CLPP (0.94 ± 0.02 mg/100 g) samples. It was largely noticed that, manganese, copper, with sodium-potassium ratio (Na^+/K^+) was low in all the analysed samples, while potassium, calcium,

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zinc, magnesium, and iron components were considerable. Meanwhile, it was observed that samples of *C. limon* proved to be important stores of potassium, calcium, magnesium, manganese and sodium in comparison to whole clementine fruit and maize. Furthermore, clementine fruit had a significantly higher content of copper and sodium-potassium ratio (Na^+/K^+), as compared to the *Citrus limon* fruit and maize.

Table 2 - Mineral components (mg/100 g) of *Citrus limon* and *Citrus clementina* fruit from a commercial farm as compared to *Zea mays L*.

Parameters (%)	CLPP	CCPP	*Zea mays L*
Calcium	603.33±20.55^a	396.67±4.71^b	10.00±4.71^c
Magnesium	130.00±0.00^a	113.33±4.71^b	100.00±0.00
Potassium	1503.33±16.99^a	1453.33±16.99^b	350.00±8.16^c
Sodium	73.33±4.71^a	43.33±4.71^b	20.00± 0.00^c
Phosphorus	173.33±4.71^b	156.67±4.71^c	233.33±4.71^a
Zinc	4.63±4.43^a	1.70±0.21^a	0.65±0.56^a
Manganese	1.00±0.08^a	0.80±1.11^b	0.50±0.00^c
Copper	0.20±2.77^b	0.27±0.05^a	0.00±0.00^c
Iron	5.23±0.23^a	3.77±0.05^b	2.90±0.59^b
Na^+/K^+	0.94±0.02^c	1.29±0.01^a	1.07±0.02^b

The letter variants along a row indicates significant differences at $p < 0.05$ among samples of *Citrus limon, Citrus clementina* and *Zea mays L*. CLPP= Citrus Limon Pulp + Peel; CCPP = Citrus Clementina Pulp + Peel. The values of components reported are mean ± standard deviation. Data is based on dry matter.

DISCUSSION

Fruits or their parts generally are known to be vital nutritional sources of nutrients for livestock, as they contain useful metabolites and bio- active compounds necessary for their growth and development (Wadhwa, 2015; Wang et al., 2019).

Moisture content has an inverse relationship with the shelf life of individual produce (Nwofia et al., 2012). Low water (moisture) content in citrus fruit (*Citrus limon* and *Citrus clementina*) and maize as recorded in present study is an indication of long storability (Ogbonna et al., 2016). Similar observation was observed by Sharif et al. (2018) in feed for lamb, however, the moisture composition of samples was higher than that of the study of Alnaimy et al. (2017), who reported only 3.5 % moisture content.

Ash content is essential in livestock nutrition since the help in the building of mineral formation. Ash was noticeably higher in content for both citrus fruit species, but lesser than yellow maize in the present study, which is in consonance with the study of Alnaimy et al. (2017). Low ash content in livestock nutrition may indicate of the presence of higher mineral elements in the feed (Adebowale and Bayer, 2002).

With regards to dietary fibre in food, their presence depicts a significant indicator, as it supports the digestive system, intestinal gut health and quickens bowel movement. Dietary fibre also lowers the amount of cholesterol when utilized by livestock (Omokore and Alagbe, 2019) suggesting that dried lemon and orange fruits as handy roughage resource materials which can be ideal as feed materials. The fibre content in the maize and both citrus fruits were comparable to the maize based animal feed (26.15 %) of Ülger et al. (2020). However, our result for crude fibre in both whole citrus fruit and maize was higher in comparison to the crude fibre of lemon pulp (11.52 %) prepared by Ülger et al. (2020), and that of citrus pulp (15.6 %) observed in the study of Wang et al (2017).

Differences in crude fibre that was observed, may be the result of the tree age of *Citrus* species, method of processing, location and individual citrus species (Audu et al., 2018). Crude fibre in the *Citrus limon* and *Citrus clementina* were less when compared to those obtained in the *Zea mays L* which is an indication of their prospect as a livestock feed resource. Dried citrus possess nutritionally significant fibre by-products, and have been utilized as feed ingredients, because they provide an environmentally stable gut biome in livestock, thereby promoting better overall animal production and performance (Steyn et al., 2017). Proteins in feed are important elements known for repairing damaged cells and they are also helpful in body-building and growth. In addition, dietary proteins assist in lowering glucoregulatory mechanism in animals (Comerford and Pasin, 2016). Dietary protein in the citrus fruit is commendable. Our result showed that the protein value in the citrus fruit and maize were in line those (6.00 % – 8. 68 %) reported by several other authors (Allam et al., 2011; Santos et al., 2014; Sharif et al., 2018; Allam et al., 2020), but they were lesser in value (14.90 %) compared to the protein content as observed in the study of Luzardo et al. (2021). Citrus can be utilized in steer's diet, because of its positive effect in improving livestock performance (Luzardo et al., 2021). Citrus fruit have also advanced the milk production of ruminants (Bampidis and Robinson, 2006; Bakr, 2020).

With respect to dietary carbohydrates, they are accountable for energy in the metabolic process in livestock (Olanipekun et al., 2016). The carbohydrate values were significantly low in citrus fruit compared to maize. However, the carbohydrate content in the citrus fruits were higher than other fruit and vegetable ingredients such as cucumber (2.17

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%), coriander (2.16 %), courgette (1.99 %), and tomatoes (2.93 %; Kamau et al., 2020). The low carbohydrate content in the citrus fruits is indicative to be a good dietary supplement (important nutrients) for animal utilization instead of the main energy source.

High starch content in grains have been reported to have a negative effect on the microbial activity in the rumen of ruminants resulting from the production of lactic acid, reducing pH in the rumen (Poulsen et al., 2012; Jacobs, 2014). The effect of high starch component in grains affects fibre degradation in a negative way which in turn also affects the performance of animals in terms of production. Meanwhile, despite the negative effect of feeding high starchy contents to livestock, it is still practiced broadly due to the high energy content that they possess, because scientist still presumes that they promote good production performance such as milk yield in animals (Steyn et al., 2017).

Dietary fats perform several significant roles in feed such as energy production, supports in cells and organs structure formation, and increase palatability of feeds (Alagbe, 2020). Ingestion of dietary fat in modest quantity is helpful to animals, but consumption in excess, negatively hampers animal health. However, some research work have attempted to use fruits and vegetable intake to cushion the effect of the high level of fats that may be consumed in the system (Djuric et al., 2002). The amount of fat in the citrus fruits and maize ranged from 2.92-4.27% in our study was in line with the findings of Alnaimy et al. (2017), and was higher than the wastes of most of the fruit and vegetable wastes such as coriander (0.09 %), courgette (0.25 %), cucumber (0.21 %), spinach (0.17 %), tomatoes (0.12 %), banana (0.50 %), mango (0.68 %), and pawpaw (0.34 %) (Kamau et al., 2020).

The mean of energy (feed ingredient) in the citrus fruit was very much lower, than in maize (330.39 %). However, the energy content of citrus fruit observed was higher than those (3.06 to 40.00 %) of other fruits and vegetables (Kamau et al., 2020). Conversely, Isong et al. (1999) reported higher energy levels of some vegetables (248.8 % to 307.1 %) compared to citrus fruit in this study.

Mineral nutrients play a vital part in supplying bio-elements in the feed of animals as a balanced diet. Dietary minerals perform numerous functions (such as metabolic and physiological processes) in animals. The mineral content of citrus fruit was significantly higher than maize, except for phosphorus. Howbeit, all the mineral contents is in the accepted amount needed in feed inclusion (McDowell, 1996). The amount of calcium in the citrus fruit was higher than the values observed for maize. The calcium content recorded in the citrus fruit was lower (1600 mg/100 g) compared to another study observed by Bampidis and Robinson (2006). The calcium content in the citrus fruit from the present finding, however, proved superior over the range (30.1 and 25.9 mg/100 g) of mandarin and lemon (Czech et al. 2020). Possible reasons for the contradictory findings could be because of the different region of study, different method of processing of the citrus, soil types, or difference in the stage of harvest of citrus fruits. Judging from the amount of calcium content present in the citrus fruit observed in our result, the citrus fruits may be ideal if added to feed for livestock utilization.

Magnesium plays multiple parts in the body functions of animals. It is important in enzyme activation. Magnesium is important in bone fortification (Kartika et al., 2011). The amount Mg present in the citrus fruit and maize samples are line to the findings by ADAS (1992) and Bath et al. (1980) in citrus, but higher in compared to the findings of Czech et al. (2020) for lemon (9.86 mg/100 g) and mandarin (11.1 mg/100 g).

Potassium helps in the physiological development of organisms (Hounsome et al., 2018). They also help to regulate water and acid base balance in the body (Indrayan et al., 2009). The potassium content for the citrus fruit was in line (620 – 1100 mg/ 100 g) with the recommendations for standard feed formulation (NRC, 1988; 2001). However, the potassium content was higher than those observed in citrus by other authors (Bampidis and Robinson, 2006; Czech et al., 2020).

Sodium plays an important role in the coordination of nerves and muscles of organisms (Akpanyung, 2005). The standard amount of Na in feed should fall within 60 – 90 mg/ 100 g for citrus (NRC, 1988; 2001), and this was in consonance with the whole lemon fruit, but higher than those of the *Citrus clementine* in our finding. Conversely, the amount of Na for *C. limon* and *C. clementina* fruits and *Z. mays* L was lower than those (100 mg/ 100 g) for citrus fruit in the study by Ensminger and Olentine (1978). However, we recorded a higher sodium value of citrus fruit than the orange fruit (30 mg/ 100 g) in another study (Bampidis and Robinson, 2006). Factors such as the type of fruits, citrus variety among others affect the amount of sodium in citrus (Wadhwa et al., 2015).

Upholding the ionic equilibrium in feeds assists the utilization of K and Na in animal nutrition. From the current study, the K and Na values could be attributed to the low Na+/K+ ratio. How it, the Na+ /K+ ratio in feed is significant most importantly if they have a ratio of less amount, which is indicative of the right Na^+/K^+ amount to advance the equilibrium of ions needed in the animal body.

With respect to phosphorus in feed, they advance calcium absorption and they also function in bone strengthening. Likewise, phosphorus performs numerous roles in the creation of several important bio-molecules required in animals including phosphoproteins (casein), phospholipids, phosphate esters (ATP), nucleic acids, hexose phosphates, as well as creatine phosphate (Alagbe, 2019). According to the standard amount of P in livestock feed by the National Research Council (NRC) which ranged between 110 to 120 mg/100 g for citrus (NRC, 1988; 2001), are in consonance with the ones in our finding. However, the values of phosphorus (17.9 and 21.8 mg/100 g) were lower to those reported in another study (Czech et al., 2020).

Zinc as an important nutritional micro-element, acts as a cofactor for several vital enzymes activity. It functions in the building formation of lipid and starch, and in the synthesis of amino acids and proteins (Bashir et al., 2020). Zinc plays a significant function in tissue repairs of the body (Miltan et al., 2014). The amount of zinc in citrus ranges between 1100

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to 1600 mg/ 100 g (NRC, 1988; 2001). The amount of zinc in the citrus fruits and maize in this study was less than (3410 mg/ 100g) those observed in another study (Alnaimy et al., 2017). However, on the contrary, the amount of Zn for citrus fruits and maize our finding was higher, than those (0.26 and 0.22 mg/100 g) reported in another study (Czech et al., 2020).

The value of Mg in diets cannot be over emphasized. Manganese plays the role of a catalyst in the synthesis of glycoproteins and lipids (Shomar, 2012). Furthermore, manganese advances the synthesis of vitamin K, and helps in skeletal development in the animal. The amount of Mg in citrus fruits and maize in our findings was in consonance with the values of manganese (0.7- 0.9 mg/100 g) as those approved for livestock (NRC, 1988; 2001). The amount of Zn in our findings was also similar to those (0.5 – 1.4 mg/ 100 g) reported in another study (ADAS, 1992). Conversely, the amount of Zn (0.07 and 0.05 mg/100 g) in citrus as observed by Czech et al (2020) was lower than the values observed in the present study.

Copper is another micro-nutrient important for pro-oxidant and they function as unsaturated fats. Copper also helps in the moderation of red blood cells. The body utilization of Cu in animals is normally very low for normal body functioning, as high copper consumption in the body can be damaging and could probably lead to liver organ damage. The amount of Cu reported in citrus fruits in our findings was similar to those (0.3 to 0.6 mg/ 100 g) observed in another study (ADAS, 1992). On the contrary, the amount of Cu reported for citrus fruits was higher compared to the amount (0.05 and 0.07 mg/ 100 g) observed by Czech et al (2020). The low amount of Cu reported for citrus fruits in our findings is commendable because they are needed in lower quantity in the body. Bampidis and Robinson (2006) also reported a low copper content for citrus from compiled results of previous studies which is in line with copper content recorded in the present study.

The body requires iron for the formation of enzymes (Lieu et al., 2001). Iron is required for transporting oxygen to all parts of the body where they are needed during respiration (Gupta et al., 2014). They also function in haemoglobin synthesis. The amount of Fe for the citrus fruits and maize were higher compared to the ones (0.29 and 0.31 mg/100g) reported in another study (Czech et al., 2020), but were lower to the ones (15.1 - 37.7 mg/ 100 g) observed by the National Research Council (NRC, 1988; 2001).

CONCLUSION

The *Citrus limon* and *Citrus clementina* fruits were found to have a reasonable amount of lipids and fibre, but with high protein contents in comparison to *Zea mays L* (yellow maize). More visibly, is the fact that the *Citrus limon* and *Citrus clementina* had rich dietary bio-active such as Na, K, Cu, Zn, Mg, Ca, Fe, and Mn, with the exception of phosphorus (P) when compared to *Zea mays L* and should therefore be considered as a rich naturally available nutrient for animal feed. Our findings also revealed the potential *Citrus limon* and *Citrus clementina* fruits as possible livestock ingredients. Since citrus fruits are relatively free of charge raw materials that is widely available in the studied area, its feeding worth as alternative feedstuff should be further researched for livestock feeding scheme which is the common source of income for most indigenous people in the region.

DECLARATIONS

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Authors' contribution
E.M. Idamokoro and Y.S. Hosu conceptualize the study.
Y.S. Hosu collected the citrus fruit.
E.M. Idamokoro did the experiment on citrus sample.
E.M. Idamokoro did data collection and analysis of citrus result.
E.M. Idamokoro wrote and edited the manuscript.

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