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A comparative analysis of the proximate and mineral composition of whole *Citrus limon* and *Citrus clementina* as a prospective alternative feed resource for livestock farming in South Africa

Emrobowansan Monday Idamokoro[1]*, Yiseyon Sunday Hosu[1], Opeoluwa Oyehan Oyedeji[2], Gugulethu Mathews Miya[3], Simon Kamande Kuria[4] and Adebola Omowunmi Oyedeji[3]

[1]Department of Economics and Business Sciences, Faculty of Commerce and Administration, Walter Sisulu University, Mthatha, South Africa, [2]Department of Chemistry, Faculty of Science and Agriculture, University of Fort Hare, Alice, South Africa, [3]Department of Chemical and Physical Sciences, Faculty of Natural Sciences, Walter Sisulu University, Mthatha, South Africa, [4]Department of Biological and Environmental Sciences, Faculty of Natural Sciences, Walter Sisulu University, Mthatha, South Africa

Citrus is a well-known vital fruit grown in South Africa. The presence of important bio-nutrients and metabolites within the different *Citrus* fruits indicates their significant nutritional qualities. This study is aimed to evaluate the proximate and mineral components of whole *Citrus limon* and *Citrus clementina* while considering them as prospective feed material for livestock farmers in South Africa. The nutritional evaluation was done using standard analytical procedures of the Association of Official Analytical Chemists (AOAC). The mineral constituents of the whole citrus samples were analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES). From the result, the nutritional analysis showed that the whole *C. limon* contains significantly higher moisture content (14.13 ± 0.57) and fiber content (24.48 ± 0.61) than *C. clementina* (11.41 ± 1.24 and 20.66 ± 1.07). Meanwhile, *C. clementina* had a significantly higher protein value (8.65 ± 0.04) compared to *C. limon* (5.53 ± 0.10). Furthermore, the whole *C. clementina* had significantly higher K, Na, P, Zn, and Na^+/K^+ (1513.33 ± 16.99, 53.33 ± 4.71, 160.00 ± 0.00, 4.80 ± 0.00, and 1.09 ± 0.01) than the whole *C. limon* (1356.67 ± 20.55, 30.00 ± 0.00, 133.33±4.71, 1.67 ± 0.09, and 0.80 ± 0.02), respectively. While *C. limon* had significantly higher Ca, Mg, Mn, and Fe (593.33 ± 4.71, 160.00 ± 0.00, 1.00 ± 0.00, and 4.53 ± 0.25) compared to *C. clementina* (483.33 ± 4.71, 136.67 ± 4.71, 0.80 ± 1.11, and 3.43 ± 0.05). The study revealed variations in some nutritional and mineral components of whole *C. limon* and *C. clementina*; however, both citrus fruits have the potential to be explored for more significant livestock nutritional use in South Africa.

KEYWORDS

citrus, nutritional evaluation, elemental composition, Eureka Lemon and Clementine, fruit

EDITED BY
Matteo Balderacchi,
Independent Researcher,
Piacenza, Italy

REVIEWED BY
Noé Aguilar-Rivera,
Universidad Veracruzana, Mexico
Luigi Liotta,
University of Messina, Italy

*CORRESPONDENCE
Emrobowansan Monday Idamokoro
midamokoro@wsu.ac.za;
mondayidamokoro@gmail.com

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Introduction

Citrus is a well-known plant comprising economically cherished species, including sweet orange, sour orange, tangerine, lemon, and grapefruit. They are among one of the widely grown fruits worldwide because of their high consumer demands. The global amount of citrus processed annually is about 31.2 million tons (Raimondo et al., 2018). An average of 1.6 million tons of citrus fruit are produced in South Africa on an annual basis. However, from the report gathered, during the processing of citrus (oranges) into juice, there is ∼50% of the total weight of the orange is discarded as waste, which includes pulp and peel (Burton et al., 2007). Furthermore, during the juicing process, a sum of 1.5 ml waste is produced per ton of fruit and contains ∼15% soluble solids and 30% pulp (Burton et al., 2007).

Citrus is an essential crop grown in South Africa and they are produced and processed on a large scale for various use including juice making (Manenzhe, 2021). South Africa is known to be a major exporter of citrus and due to its abundance in the country, it could be of great economic and nutritional benefits to the farming industry (Department of Agriculture, 2019). Citrus fruits possess several bio-compounds/bio-nutritional components, such as heraclenin, imperatorin, auraptene, bergamottin, carotenoids, flavonoids, dietary fiber, essential oils, sugars, polyphenols, ascorbic acid, as well as micro- and macro-minerals, whose presence increases its therapeutic and dietary value (Genovese et al., 2014).

The low cost and readily available whole (pulp and peel) citrus can be converted into a more useful source of animal feed and nutraceuticals (Rafiq et al., 2018). They can also be utilized to yield functional foods or dietary supplements, providing not only dietary fiber and antioxidant compounds, but also minerals (Barros et al., 2012; Czech et al., 2020). Due to the presence of a large amount of nutritional value, the rind of citrus is sometimes dried, mixed with dried pulp, and utilized for large ruminant feed such as cattle (Bocco et al., 1998; Zema et al., 2018).

The ever-growing need to source for other potential unconventional feedstuff to enhance livestock farming both at small-scale and industrial levels in most countries, especially in developing countries cannot be overemphasized. The reason is that conventional animal feedstuffs are becoming costly and most livestock farmers in developing countries (South Africa inclusive) may prefer a much cheaper feed alternative. Livestock and especially ruminant feeding systems based on naturally abundant by-product feedstuffs (BPF) are often a practical alternative because the rumen's microbial ecosystem can utilize BPF that often contains high levels of structural fiber to meet their nutrient requirements for growth, maintenance, production, and reproduction performance. The presence of high pectin in citrus gives room for a faster rumen fermentation, thereby allowing the release of energy for fast microbial growth (Hall et al., 1988), and this contributes to building better rumen conditions in livestock for fiber fermentation. Furthermore, the high level of prospective degradable dry matter (DM) offers a high total digestible nutrient content (De Peters et al., 1997). However, the addition of citrus by-products in the diet of small dairy ruminants has been reported to show some effect on milk composition, milk yield, milk traits/properties, and the quality of derived products (Jaramillo et al., 2009). According to Salvador et al. (2014), the inclusion of citrus pulp into goat's diet had an effect on the milk quality and cheese composition, which resulted in a lower pH and water activity, high fat and NaCl composition that contribute to advancing the sensory traits of derived ripened cheese. In addition, the inclusion of citrus by-products in ewe's diet showed a promising feeding tendency of the animal, and it had a positive effect on the milk component and cheese from ewes (Liotta et al., 2019).

The current bulk of citrus fruits from major citrus farms in South Africa could be explored to provide citrus fruits (by-products), which could be helpful in cementing the nutritional breach that is encountered in animal feed, thereby preventing the competition between human and livestock for edible grains consumption. Exploring the potential of whole citrus fruits (pulp and peel) as animal feed to advance livestock farming requires further investigation (Ülger et al., 2018). Pereira et al. (2007) reported that citrus fruit parts (pulps, peels, and their parts) reduced feed costs and increased profitability in livestock farming. Furthermore, Ülger et al. (2020) reported that citrus is a vital alternative feed source in animal nutrition.

In South Africa, livestock husbandry is the largest agricultural sector, accounting for more than 40% of agricultural production's total worth and occupying an estimated 80% of readily available agricultural land (Casey, 2021). In rural regions of South Africa, animal farming is often the main income generator and a major form of social capital. Although it can be said that primary agriculture contributes a relatively small share of the country's GDP; however, it plays a vital role in job creation and earning foreign exchange through exports (Casey, 2021). It should be noted that the major strength of South Africa's livestock production rest in its well-established private sector and its support for small and emerging commercial farmers.

Extensive livestock farming with cattle, sheep, and goats in pastoral production systems and chickens and swine around settlements was well established among the southern African people for many centuries. The indigenous livestock is naturally highly adapted to the range of climatic and seasonal variations of the nutritional value of natural herbage. Making use of the extensive rangeland for livestock farming (with cattle, sheep, and goats) is the major driver of the livestock industry producing a variety of products, and sustaining vast numbers of employees and dependents (Meissner et al., 2013a,b). In addition, it has been reported that the livestock sector occupies 79% of the agricultural land and it employs more than 21% of the agriculture workforce (Statistics, 2020).

According to statistics, South Africa has 12.8 million cattle, 19.4 million sheep, 3 million goats, 1.5 million swine (DALRRD., 2020), and 38.2 million poultry (SAPA., 2019). Animal production's gross value is 46% of the agricultural gross value. Within the livestock sector of South Africa, there are 40% of cattle products, 39% of poultry meat and eggs, and 10% of sheep and goat products. The livestock sectors are designed as extensive, semi-intensive, and intensive production systems. Extensive primary production systems are beef, wool and meat, and mohair-producing goats. The extensive system of livestock production in South Africa utilizes natural range, which are valuable available feed resource for livestock.

Citrus fruits as a by-product can be gathered in large quantities and processed as a prospective periodic livestock feed source to improve animal production (Steyn et al., 2017). Conversely, there is merit in evaluating the utilization of whole citrus fruit as an alternative livestock feed resource in South Africa as it could proffer an alternative or complementary/supplementary feed ingredient for livestock farmers. This may largely be because of the continuous increase in the price of grains which is a major livestock feed for animals among other reasons (e.g., drought and low financial resources by local farmers). Processed citrus fruits as by-products could be fed to livestock as stand-alone feed, but they can be preserved for a longer period when dried and kept in a cool environment, thus forming a significant part of the annual feeding plan for animal farming (Steyn et al., 2017).

The aim of this study was to compare the nutritional and mineral attributes between the whole (peel + pulp) citrus fruits of *Citrus limon* and *Citrus clementina* and to determine which citrus fruit, among them, is the richest in nutrients and minerals. We also discussed the prospect of using the whole (peel + pulp) citrus fruits of *C. limon* and *C. clementina* as livestock feed resources for indigenous farmers in South Africa. In this study, we stuck with the use of whole *C. limon* and *C. clementina* fruits because they are the most abundantly available citrus fruit that shows promising prospects to be used as an alternative (or supplementary feed material) livestock feed since they are widely grown in the study area.

Materials and methods

Collection of whole citrus fruit

The whole *C. limon* and *C. clementina* fruits were collected from a commercial citrus farm (Greenwood farm). The citrus fruits that were collected were the ones that naturally fell around the surrounding of the farm. They were then taken to the laboratory for further processing. The whole *Citrus* fruits collected from the farm included *C. limon* (Eureka Lemon) and *C. clementina* (Clementine), which were the majorly grown citrus fruits in the region. The citrus farm is located in the Central Eastern Cape Province of South Africa and it has a geographical latitude and longitude of 26°22'24.32''.

Preparation of whole *Citrus limon and Citrus clementina* fruits before analysis

The whole *Citrus* fruit as described in the present study is a combination of both the pulp and peel of *C. limon* and *Citrus clementina,* which were cut into sampler pieces before they were dried in the sun (solar drying) till they were considerably sapped of their juice/fluid. After air-drying, the *Citrus* fruit was again dried in an oven (LABOTEC, Durban, South Africa) at 50°C for 2 days (48 h) in order to achieve the needed dried citrus sample and to evade high temperature-induced loss of extremely volatile metabolites from the samples. Afterward, the *Citrus* fruits (pulps + peels) were crushed after drying into smaller granules with a blender (Hamilton Beach HBF 500 Series, Virginia, USA). The crushed materials were then nicely packed into sample plastic bags and they were labeled before carrying out further analysis.

Evaluation of the nutritional components of whole *Citrus limon and Citrus clementina* fruits

Determination of moisture content

The moisture content of the ground citrus fruit samples was carried out using the procedure by the (Association of Official Analytical Chemists (AOAC), 2000). A dried and blank weighing dish was weighed (W_x) in the oven (LABOTEC-South Africa) to obtain its initial weight. The dried citrus fruit sample was later placed inside the initially weighed dish and then weighed again (W_y) before it was dried in an oven for 72 h at a temperature of 40°C to get a constant weight. The oven-dried sample was then allowed to cool and reweighed (W_z).

The percentage (%) of moisture content was given as follows:

$$\text{Moisture content}(\%) = \frac{W_y - W_z}{W_y - W_x} \times 100$$

Where,

W_x is the weight of the empty dish,

W_y is the weight of the dish + dried whole citrus fruit sample before drying,

W_z is the weight of the dish + dried whole citrus fruit samples.

Determination of ash content

The ash content of the dried whole citrus fruits was obtained using the dry ash technique (Agrilasa, 2007). The sample dish was dried at a temperature of 105°C for 1 h after which the dish was weighed when cooled (W_x). After that, 2 g of the dried citrus fruit samples were put in the weighed dish and weighed for a second time (W_y). The dish with the citrus samples was then ashed at a temperature of 250°C for an hour in a burner (Furnace E-Range, E300-P4, MET-U-ED South Africa). Afterward, the ashed fruit samples were allowed to cool before weighing again (W_z).

Calculation of ash content

$$\text{Ash content (\%)} = \frac{W_x - W_z}{W_y - W_x} \times 100$$

Where,

W_x is the weight of the dried dish,

W_y is the weight of the dish + whole citrus fruit sample,

W_z is the weight of the dish + ashed whole citrus fruit sample.

Determination of crude protein

The approximation of crude protein was calculated from the total nitrogen (TN) component in the citrus fruit sample from the micro Kjeldahl procedure (Hussain et al., 2011). Two grams of the dried citrus fruit sample were digested in a Kjeldahl flask. This procedure was done by heating 20 ml of concentrated tetra-sulfate acid (H_2SO_4) and a digestion tablet in the flask in order to allow for the appearance of the clear mixture (i.e., citrus fruit sample powder + H_2SO_4). The digest from the mixture substance was filtered and poured into a 250 ml volumetric flask containing distilled water, after which it made up to the required mark. This process was done to allow proper distillation procedure and ammonia to steam-distilled from the digest into which a 50 ml of 45% NaOH solvent was poured into the flask. A measure of 150 ml of the distillate was later added into a conical flask having 100 ml 0.1 N hydrochloric acid. The nitrogen content of the citrus fruit sample was now calculated by back-titrating against 2 M sodium hydroxide (NaOH) using methyl orange as the standard indicator.

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

Where,

N is the normality,

1.4007 is used as the single factor of nitrogen molecular weight,

Crude protein = nitrogen content (sample) × 6.25

Determination of crude fiber

The content of the dietary fiber of the citrus fruit sample was determined by utilizing the modified acid–base digestion technique (Aina et al., 2012). Five grams of dried citrus fruit powder was digested by heating the sample with 100 ml of 0.25 M sulphuric acid solution for 30 min under reflux action. The mixture was then filtered to separate the fluid from the filtrate after which the filtrate was rinsed four times with boiled water to remove the residue acid content in the filtrate. This process was carried out for a second time on the filtrate with 100 ml of 0.31 M sodium hydroxide (NaOH) solution before the final residue was washed with distilled water to take out any form of the base in the filtrate. After washing, the filtrate was then oven-dried at a temperature of 100°C, before it was cooled in a desiccator and then weighed (C_x). The weighed sample was then incinerated at 550°C for 2 h and then left to cool in a desiccator before being weighed (C_y).

Calculation of crude fiber content (%)

$$\text{Crude fiber (\%)} = \frac{C_y - C_x}{\text{Weight of Sample}} \times 100$$

Determination of crude lipid

The crude lipid of the citrus fruit dried powder was determined using the Soxhlet extraction techniques (Al-Harrasi et al., 2012). The content of crude lipid was gotten from 5 g of the citrus fruit sample with 100 ml ether solvent. Thereafter, the solution was filtered, and the residual lipid filtrate was poured into a weighed clean 500 ml round bottom flask (W_x). The sample lipid extraction was wholly done with 100 ml petroleum ether for 24 h. The solution obtained was then filtered and poured into the round bottom flask. The lipid constituent was there after being concentrated to a dry condition in a steam bath before it was later oven-dried at 50°C. The flask was then weighed again (W_y).

Calculation of lipid was quantitatively done using the formula:

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

Determination of total carbohydrate content

The carbohydrate content of the dried citrus fruit was carried out by deducting total protein, crude fiber, ash content, lipid, and crude fiber from the sum of dry matter using the formula below:

Total carbohydrate (%) = 100 – (% moisture content + crude fiber + total ash + crude lipid + crude protein).

Determination of energy value

The sum total of the energy value of the dried whole citrus fruit samples was obtained by using the Atwater factors as given: 4 kCal, 9 kCal, and 4 kCal to ascertain the caloric value. The aggregate of the multiplied lipid, carbohydrate, and crude protein values is given in the formula below:

Energy value (kCal/100 g) = (crude protein × 4) + (total carbohydrate × 4) + (crude lipid × 9).

Determination of mineral element constitution

Mineral element analysis was done to quantitatively determine mineral constituents in the whole citrus fruits. The analyzed elements from the whole citrus fruit were both macro elements (calcium, magnesium, phosphorus, potassium, and sodium) and microelements (copper, manganese, iron, and zinc) using the ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer; Varian 710-ES Series, SMM, Cape Town, South Africa). All analyzed samples of the whole *C. limon* and *C. clementina* fruit were done in triplicate.

Data analysis

The data obtained from the analysis of whole citrus fruit samples of *C. limon* and *C. clementina* were expressed as mean ± standard deviation and they were further subjected to a one-way analysis of variance (ANOVA) by the use of MINITAB 19 statistical package. Analysis of Variance (ANOVA) was derived from Fischer's pairwise comparisons (Fisher LSD at 95% confidence). Statistical differences were measured at $p < 0.05$. Letter variations along a row of whole *C. limon* and *C. clementina* fruit for each parameter show significant differences at $p < 0.05$.

Results

Proximate composition of whole *Citrus limon* and *Citrus clementina* fruit

The proximate contents of whole *C. limon* and *C. clementina* obtained from the Greenwood commercial citrus farm are shown in Table 1. From the result, the nutritional analysis showed that the whole *C. limon* contains significantly higher moisture content (14.13 ± 0.57) and fiber content (24.48 ± 0.61) than *C. clementina* (11.41 ± 1.24, and 20.66 ± 1.07), respectively. Meanwhile, *C. clementina* had a significantly higher protein value (8.65 ± 0.04) compared to *C. limon* (5.53 ± 0.10).

TABLE 1 Proximate composition (%) of whole *Citrus clementina* and *Citrus limon*.

Parameters (%)	*Citrus clementina*	*Citrus limon*
Moisture	11.41 ± 1.24^{b}	14.13 ± 0.57^{a}
Ash	5.44 ± 0.02^{a}	5.47 ± 0.05^{a}
Lipid (Fat)	3.19 ± 0.16^{a}	3.29 ± 0.09^{a}
Carbohydrate	16.04 ± 21.21^{a}	1.73 ± 0.66^{a}
Protein	8.65 ± 0.04^{a}	5.53 ± 0.10^{b}
Fiber	20.66 ± 1.07^{b}	24.48 ± 0.61^{a}
Caloric value	127.25 ± 85.26^{a}	58.66 ± 2.63^{a}

Values shown are mean ± standard deviation, while letter variations along a row indicate significant differences at $p < 0.05$ among samples of whole *Citrus limon* and *Citrus clementina*.

Mineral composition of whole *Citrus limon* and *C. clementina* fruit

Tables 2, 3 showed the results of the comparative macro and micro elements of whole citrus fruit from *C. limon* and *C. clementina* obtained from Greenwood commercial citrus farm. The whole *C. clementina* had significantly higher K, Na, P, Zn, and Na+/K+ (1513.33 ± 16.99, 53.33 ± 4.71, 160.00 ± 0.00, 4.80 ± 0.00, and 1.09 ± 0.01) than the whole *C. limon* (1356.67 ± 20.55, 30.00 ± 0.00, 133.33 ± 4.71, 1.67 ± 0.09, and 0.80 ± 0.02), respectively. Furthermore, the whole *C. limon* had significantly higher Ca, Mg, Mn, and Fe (593.33 ± 4.71, 160.00 ± 0.00, 1.00 ± 0.00, and 4.53 ± 0.25) compared to the whole *C. clementina* (483.33 ± 4.71, 136.67 ± 4.71, 0.80 ± 1.11, and 3.43 ± 0.05), respectively.

Discussion

Fruits commonly are recognized to be an important nutrient source for both livestock and humans (Wadhwa, 2015). The significance of fruits in diets is that they contain beneficial metabolites and a bioactive substance present in their various parts, and these substances contribute to the wellbeing of animals (Wang et al., 2019). The replacement levels of dried citrus pulp (DCP) in formulated feeds for example vary according to the availability and relative cost-effectiveness of alternative raw materials (Bakr, 2020). The replacement levels ranged from 8 to 100% with an energy source (Shdaifat et al., 2013; Santos et al., 2014; Allam et al., 2020).

The liquid content otherwise known as moisture content is an important attribute for the shelf-life span of plants, with high moisture contents signifying a lower shelf-life (Uyoh et al., 2013). The moisture content in the whole *C. limon* was significantly higher than that of *C. clementina* but both whole citrus fruits had quite low-moisture content, which may be an indication of a possible long shelf-life of the fruits

TABLE 2 Macro elemental composition (mg/100 g) of whole *Citrus clementina* and *Citrus limon.*

Parameters (mg/100 g)	*Citrus clementina*	*Citrus limon*
Calcium	483.33 ± 4.71^{b}	593.33 ± 4.71^{a}
Magnesium	136.67 ± 4.71^{b}	160.00 ± 0.00^{a}
Potassium	1513.33 ± 16.99^{a}	1356.67 ± 20.55^{b}
Sodium	53.33 ± 4.71^{a}	30.00 ± 0.00^{b}
Phosphorus	160.00 ± 0.00^{a}	133.33 ± 4.71^{b}
Na^{+}/K^{+}	1.09 ± 0.01^{a}	0.80 ± 0.02^{b}

Values shown are mean ± standard deviation, while letter variations along a row indicate significant differences at $p < 0.05$ among samples of whole *Citrus limon* and *Citrus clementina.*

(Alagbe and Betty, 2019). The moisture contents recorded for the whole *C. limon* and whole *C. clementina* fruits were higher than the citrus fruit (3.5%) reported by Alnaimy et al. (2017) and the citrus fruit value (9.50%) reported by Sharif et al. (2018), who used it as a supplement to feed lambs.

Ash content in feed materials is vital in the diet of animals for the reason that it has a significant linkage to mineral element configuration (Oyeyinka and Afolayan, 2019). Ash content was appreciably available in both the whole *C. limon* and *C. clementina* fruits. Our results for the whole *C. limon* and *C. clementina* fruit were in line with the values (ranging from 3.1 to 8.4%) that were reported by Alnaimy et al. (2017). Lower ash content when used as a supplement in feeds may be an indication of abundant minerals in the material (Adebowale and Bayer, 2002).

The presence of dietary fiber in food is a vital pointer to its quality because it helps both the intestinal gut health and quickens bowel movement and the digestive system of the body (Oyeyinka and Afolayan, 2019). Dietary fiber also reduces serum cholesterol levels when consumed by animals (Omokore and Alagbe, 2019). The presently studied citrus fruits possess a commendable amount of fiber, thus suggesting that they can be an important roughage source that could be suitable as feed ingredients. The result for crude fiber in both whole *C. limon* and *C. clementina* fruits were higher compared to the crude fiber of dried citrus pulp (15.6%) as reported by Wang et al. (2019) and lemon fruit (11.52%) as reported by Ülger et al. (2020). In the present study, the differences in the crude fiber were observed between the whole *C. limon* and *C. clementina* fruits may largely be due to the difference in the citrus species (Audu et al., 2018). Dried whole citrus fruit is a rich source of fiber and when used as livestock feed in a total mixed ration (TMR) feeding scheme since it supplies a stable ruminal environment in ruminants, thereby improving animal productivity (Steyn et al., 2017).

Dietary proteins are vital nutrients in repairing impaired tissues and for body-building processes in animals. Meanwhile, it has been reported that they play a functional role in plummeting glucoregulatory mechanisms in animal bodies (Comerford and Pasin, 2016). The protein content in both the whole *C. limon* and *C. clementina* fruits is relatively high, and this could make them useful protein supplements in diets with *C. clementina* having an edge over *C. limon* fruit. The result of the protein content from the whole *C. clementina* fruit was in consonance with the protein content (ranged between 6.00% and 8. 68%) of dried *Citrus* and orange fruit, which was reported by several other authors (Bampidis and Robinson, 2006; Allam et al., 2011, 2020; Palangi et al., 2013; Santos et al., 2014). However, the value of protein content in the whole *C. limon* and *C. clementina* fruits was lesser in value when compared to the one (14.90%) reported by Luzardo et al. (2021). Fresh citrus fruits can be used in diets for feedlot steers as it was reported to give a positive effect on animal productivity, especially as a result of a positive result on their dry matter intake and a better feed to weight gain ratio of the animal (Luzardo et al., 2021). Citrus fruit by-products have also been used to improve the performance and milk production of sheep and other ruminants (Bampidis and Robinson, 2006; Zoiopoulos et al., 2008; Bakr, 2020).

TABLE 3 Micro elemental composition (mg/100 g) of whole *Citrus clementina* and *Citrus limon*.

Parameters (mg/100 g)	*Citrus clementina*	*Citrus limon*
Zinc	4.80 ± 0.00^{a}	1.67 ± 0.09^{b}
Manganese	0.80 ± 1.11^{b}	1.00 ± 0.00^{a}
Copper	0.40 ± 5.55^{a}	0.4 ± 5.55^{a}
Iron	3.43 ± 0.05^{b}	4.53 ± 0.25^{a}

Values shown are mean ± standard deviation, while letter variations along a row indicate significant differences at $p < 0.05$ among samples of whole *Citrus limon* and *Citrus clementina.*

Carbohydrates are known to be responsible for providing energy during body metabolism in animals and they are also produced during photosynthesis in plants (Olanipekun et al., 2016). In addition, carbohydrates are also very vital for supplying glucose for brain functioning. The carbohydrate content in the whole *C. clementina* fruits from the present study was higher compared to fruit and vegetable wastes from cucumber (2.17%), coriander (2.16%), tomatoes (2.93%), and spinach (2.38%) as reported by Kamau et al. (2020). The low level of carbohydrate content in the whole *C. limon* was comparable to courgette fruit (1.99%) reported by Kamau et al. (2020).

The content of carbohydrates in the whole *C. clementina* fruit indicates that they can serve as an energy feed source in livestock diets and they may also be used as supplements for animal utilization.

Dietary lipids assist in energy production, increase the palatability of feeds, transportation of vital vitamins, and support the structural functioning of cells and organs (Alagbe, 2020). The ingestion of dietary fat at a moderate level can be beneficial for healthy nutrition, but when in excess, dietary fat ingestion may negatively affect animal health. Several research studies have also tried to exploit the use of fruit and vegetable intake in a bid to regulate fat levels in the animal body (Djuric et al., 2002). The fat content in the whole *C. limon* and *C. clementina* in the present study was in line with the ones (ranges from 1.3% to 9.1%) reported by (Alnaimy et al., 2017).

The mean value for the energy content of each of the components of the whole *C. limon* was relatively low compared to the whole *C. clementina* fruit. The low carbohydrate, moderate lipid, and protein levels were noticeable in the derivative energy contents for the whole *C. limon* in this study. The energy values for the whole *C. limon* and *C. clementina* fruits in our study were higher compared to the ones reported for fruits and vegetable wastes, which ranged from 3.06 to 40.00% (Kamau et al., 2020). However, the energy values for the whole *C. limon* and *C. clementina* fruits were lower compared to the energy contents of some vegetables (248.8–307.1%) reported by Isong et al. (1999).

Dietary elements are vital ingredients that are largely involved in providing bio-molecules in animal feed to balance animal diets. Dietary elements perform significant functional roles, including structural, physiological, and metabolic processes in the animal body. The macro and micro mineral content in the current study reveals that the whole *C. limon* and *C. clementina* fruits fall within the ones endorsed by the World Health Organization guidelines (WHO, 1991).

The calcium content of whole *C. limon* and *C. clementina* fruits revealed in the present study was lower compared to the one (1,600 mg/100 g) reported by Bampidis and Robinson (2006). However, the calcium contents in the whole *C. limon* and *C. clementina* fruits in the present study were higher compared to the values (30.1 and 25.9 mg/100 g) recorded for mandarin and lemon fruits, respectively, by Czech et al. (2020). The reason for the variation of results may be due to different regions where these studies were conducted, soil types where the citrus species were grown, the method of processing of the citrus species, and the stage of the harvest of citrus species. Calcium plays a significant role in bone strengthening and rigidity in animals (Ibrahim et al., 2001), but its absence in diets may lead to tetany. Observing the amount of calcium present in whole *C. limon* and *C. clementina* fruits is indicative that they may be an appropriate supplementary source of calcium for livestock feed.

Magnesium is a very vital macro mineral in diets because of the multiple roles that it plays in animal body functions. Magnesium helps to activate muscle and nerve contractions and it is very important in enzyme stimulation. Magnesium functions actively in carbohydrate, protein, and lipid metabolism it also involves in the regulation of intracellular acid-base balance (Beldi et al., 2006). Furthermore, magnesium is vital in bone and tooth strengthening (Kartika et al., 2011). The magnesium content in the whole *C. limon* and *C. clementina* fruits in the present study were comparable to those reported by Bath et al. (1980) and ADAS (1992) in dried *Citrus* fruits, but higher in values than those (11.1 and 9.86 mg/100 g) reported by Czech et al. (2020) for mandarin and lemon fruits, respectively.

Potassium performs functional parts in the physiological processes of living organisms (Hounsome et al., 2018) and they are involved in the regulation of water and acid–base equilibrium in the body and muscle function (Indrayan et al., 2009). The potassium contents for the whole *C. limon* and *C. clementina* fruits in the present study were higher than the ones (620–1,100 mg/100 g) reported by the National Research Council (NRC) for livestock feed composition [(National Research Council (NRC)., 1982, 1988, 2001)]. The potassium in the current study was also higher compared to the citrus fruit values (820 mg/100 g) reported by Bampidis and Robinson (2006) and the value (133 and 120 mg/100 g) reported by Czech et al. (2020) for mandarin and lemon fruits, respectively.

Sodium is involved in a significant role in the function of the nerve and muscle contraction and plasma volume of animals (Akpanyung, 2005). The value for sodium content for livestock feed composition as recorded by the National Research Council falls within 60–90 mg/100 g for dried *Citrus* fruit and dried orange fruit [(National Research Council (NRC)., 1982, 1988, 2001)] and was slightly higher compared to the whole *C. limon* fruit, but comparable to that of the whole *C. clementina* fruit in the present study. The value of sodium content of the whole *C. clementina* fruit was higher compared to the value of dried orange pulps (30 mg/100 g) that was reported in the study by Bampidis and Robinson (2006). However, the value of sodium content in the whole *C. limon* fruit was in consonance with the one reported by Bampidis and Robinson (2006). Factors such as the geographical area and plant physiological which include, the source of the fruit, type of processing, citrus variety, the citrus species, and the period of harvesting have been identified to influence the sodium contents of citrus species (Arthington et al., 2002; Wadhwa et al., 2015). These aforementioned factors could be a possible reason for the variation in the result of sodium content from the present study as compared to other studies.

Maintaining the balance in ions during feed formulation helps to utilize the content of potassium and sodium in diets. The mean values for potassium and sodium content are accountable for the observed low Na+/K+ ratio as was observed in the present study. However, this ratio in the diet is essential, especially with a ratio of fewer values as seen in our result, which is an ideal Na+/K+ that will improve the balance of ions in feed and extension in the animal body.

Phosphorus is known to improve calcium absorption and it helps to strengthen bones and teeth in animals. Phosphorus is also involved in several aspects such as the creation of vital compounds needed in the body including nucleic acids, phospholipids, phosphoproteins (casein), hexose phosphates, phosphate esters (ATP), and creatine phosphate (Alagbe and Betty, 2019). The reported value by the National Research Council (NRC) for phosphorus content in livestock feed ranges between 110 and 120 mg/100 g for dried citrus pulp, dried orange pulp, and citrus pulp silage [(National Research Council (NRC)., 1982, 1988, 2001)] and are lower to the values reported in the whole *C. limon* and *C. clementina* fruits as revealed in the present study. This indicates that the whole *C. limon* and *C. clementina* fruits in the present study have a good prospect to be used for animal feed. Furthermore, the result for the phosphorus content in whole *C. limon* fruit as seen in the present study is in line with the values (110–150 mg/100 g) compiled from the results of a previous study by Bampidis and Robinson (2006) and Alnaimy et al. (2017), but it had higher value of phosphorus content compared to the ones (17.9 and 21.8 mg/100 g) reported by Czech et al. (2020) for mandarin and lemon fruits, respectively.

Zinc plays a vital role in the building process of starch and lipid, most importantly in the synthesis of proteins and amino acids (Bashir et al., 2020). Although zinc is seen as a micronutrient, its role in the repair of body tissues and the cerebral growth of animals cannot be over-emphasized (Mlitan et al., 2014). The value for zinc content in the whole *C. limon* and *C. clementina* fruits in our study was low in comparison with the value (3,410 mg/100 g) reported by Alnaimy et al. (2017). However, the values of zinc content for the whole *C. limon* and *C. clementina* fruits from the present study were higher compared to the values (0.26 and 0.22 mg/100 g) reported for mandarin and lemon as reported by Czech et al. (2020).

Manganese is another mineral in diets that is very important because they act as a catalyst and co-factor in the synthesis of lipids and glycoproteins (Shomar, 2012). In the same vein, manganese improves the synthesis of prothrombin together with vitamin K as they support skeletal growth and development in the body. The mean values of whole *C. limon* and *C. clementina* fruits in the present study were similar to the values (0.7–0.9 mg/100 g) for dried citrus pulp and dried orange pulp reported by the National Research Council (NRC) for manganese content in livestock feed [(National Research Council (NRC)., 1982, 1988, 2001)]. The value of zinc content in the present study was also similar to the ones (0.5–1.4 mg/100 g) reported by ADAS (1992). However, the value of zinc content in the present study was higher compared to the ones (0.07 and 0.05 mg/100 g) reported for mandarin and lemon fruits by Czech et al. (2020). The value of zinc content from our result shows that the whole *C. limon* and *C. clementina* fruits can be a good supplementary source of manganese in livestock feed.

Copper is an essential pro-oxidant and it acts as a catalyst in the oxidation of unsaturated lipids along with ascorbic acid. Copper also assists in the regulation of red blood cells in living organisms. The requirement of copper in the body is generally low because high copper consumption can damage the liver. The value of copper content reported for the whole *C. limon* and *C. clementina* fruits is in consonance with the values (ranging from 0.3 to 0.6 mg/100 g) reported by ADAS (1992) and Bampidis and Robinson (2006) for citrus pulps. However, the values of copper contents reported for the whole *C. limon* and *C. clementina* fruits were higher in comparison to the values (0.05 and 0.07 mg/100 g) reported by Czech et al. (2020). The low copper content reported for the whole *C. limon* and *C. clementina* fruits is commendable since they are required in a lower amount in the body.

Iron in diets is required for the formation of heme enzymes and other iron-containing enzymes in the body (Lieu et al., 2001). Furthermore, iron is responsible for transporting oxygen from the lungs to the cells and tissues of the body during breathing (Gupta et al., 2014). Iron is also known to function in the synthesis of hemoglobin, and the oxygenation of other nutrient substrates such as carbohydrates, fats, and proteins. The iron content for the whole *C. limon* and *C. clementina* fruits was higher compared to the values (0.29 and 0.31 mg/100 g) for mandarin and lemon as reported by Czech et al. (2020).

Conclusion

The study revealed that the whole *C. limon* and *C. clementina* fruit had substantial quantities of nutritional components such as protein, lipids, and fiber among others, but *C. clementina* had a significantly higher protein content when compared to *C. limon* fruit. In addition, both the whole *C. limon* and *C. clementina* fruits contain significant dietary macro and micro elements such as Mg, Ca, Na, K, P, Cu, Zn, Fe, and Mn and may, therefore, be considered a rich naturally available ingredient source for livestock feeding based on the revealed presence of nutritional components of the plant. However, there were significant variations in the mean values of the mineral contents between the whole *C. limon* and *C. clementina* fruits for all the measured parameters except for copper. The present study also suggests the possible prospect of whole *C. limon* and *C. clementina* fruit to be put to more relevant livestock nutritional use, since both whole *C. limon* and *C. clementina* fruit can be obtained for free (without charge) as waste by farmers from large citrus farms because they are widely abundant in the studied area. Exploring more research on the utilization of citrus fruits in a feeding scheme for livestock is worth the while since they appear to be a sustainable alternative or supplementary feed resource and should be further investigated.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

EI did data collection and analysis and wrote the main text. All authors reviewed the manuscript, conceptualized the study, contributed to the article, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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