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Research Article

Provisional Classification of Wild Edible Fruits Based on their Nutrient Profiles

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Abstract

Nutritional analyses of food have mainly focused on determining the nutritional composition. Few concentrate on their nutritional value. This study provisionally classified ten wild edible fruit types (WEF) growing in the Teso sub region in eastern Uganda by their nutritional value. Fruit pulps of Carissa spinarum, Saba comorensis, Sclerocarya birrea. Flacourtia indica, Vitex doniana, Strychnos spinosa Ximenia americana., Vangueria infausta, Vitellaria paradoxa and Physalis minima. were analyzed for proximate and mineral composition, and their recommended dietary allowance (RDA) per 100g were calculated. Hierarchical Cluster Analysis (HLA), Principal Components Analysis (PCA), and Canonical Discriminant Analysis (CDA) were used to classify the fruits based on their nutrient compositions. Then the pulps were profiled for nutrients composition using the nutritious food index (NFI) model. The HLA returned two and three clusters at linkage distances of <25 and 15 respectively, showing that these clusters were nutritionally distinct from each other. The PCA returned five components which accounted for 86.27% of the variability in the nutritional composition. The variability in Principle Component I was explained primarily by differences in moisture, total energy and total carbohydrates and that in Principle Component 2 mainly by dissimilarities in amounts of Zn and Fe. Canonical Discriminant Analysis (CDA) generated three Canonical Discriminant Functions (CDF), the first of which explained 99.2% of the total variation of the clusters with total carbohydrate and potassium quantities as the major contributors (Wilks' lambda: Λ = 0.173 and 0.041 for carbohydrates and potassium respectively). The nutrient density profiles had F. indica and P. minima as the top-ranked with their overall nutritional values largely contributed by protein, potassium and dietary fibre. These results suggest that classification of WEFs based on nutritional composition is possible, and these could be used in their promotion among communities in public health and nutrition education.

Keywords: Indigenous Fruits; Nutrient Profile; Nutritional Composition; Hierarchical Dendrogram Clustering; Principal Component Analysis; Provisional Classification

Abbreviations

WEF: Wild Edible Fruits; RDA: Recommended Dietary Allowance; HCA: Hierarchical Cluster Analysis; NFI: Nutritious Food Index; CDA: Canonical Discriminant Analysis; CDF: Canonical Discriminant Functions; PC: Principal Component; GDA: General Discriminant Analysis

Introduction

The World Health Organisation (WHO) estimates that nearly two billion people worldwide suffer from hidden hunger due to micronutrient deficiencies. This undernutrition has been linked to increased disease burden among children, especially in developing countries resulting in their early death. It is estimated that globally 5.3 million children are likely to die before their fifth birthday [1]. The cause of malnutrition in developing countries has been linked to dependence on staple foods such as cassava, potatoes, maize and rice which are high in calories and deficient in essential micronutrients. There is a strong scientific notion that such energy dense staple foods are nutrient-poor [2]. However, wild indigenous edible fruits (WEF) that form an integral part of household diet, culture and tradition in developing countries can be healthful since they are considered to contain substantial amounts of micronutrients including essential vitamins and minerals.

With a global drive for countries to develop national food composition databases to address health and nutrition challenges, the nutritional values of WEF are crucial. For decades' scientists have been conducting various studies on the nutritional composition of various species of WEF [3-6], but this information has not been fully utilized in nutrition guidance or education or product formulation. Perhaps analyses conducted on these WEF focus on establishing individual nutrient contents in each fruit rather than the overall nutritional value. With variability in the nutrient content of WEFs, even of the same species in different locations, it's difficult to conduct nutritional public health education on which species are important without assessing the overall nutritional value. According to Jomaa., *et al*. (2016) even within each food group, different foods can vary greatly in their nutritional quality despite often having similar energy (caloric) values. Consequently, scientists attempt to promote WEF based on one nutrient in high concentration e.g., vitamin C or A, Zn or Fe, and ignoring most other nutrient's contributions. According Katz., *et al*. (2009), using individual nutrients alone to promote food cannot adequately convey the overall nutritional quality of any food.

In the past, recommended dietary allowances (RDAs) were used to rank foods by their nutrient contents across and within food groups, but this was found to have some drawbacks as many nutritious foods got disqualified due to the focus on specific nutrients with particular concentrations rather than the overall nutritional value [6]. At the time, the overall nutritional quality index was developed as a nutritional rating system where foods were assigned a score between 1 and 100 (Higher scores represent greater overall nutritional value) taking into consideration the relative portions of nutrients like vitamins, sugar, sodium, protein and fat. This type of rating found vegetables and fruits with the highest scores while soft drinks received the lowest.

Currently, studies that attempt to establish the nutritional values of WEF based on the overall nutritional value for their promotion as routine foods are limited. Identification of the best approach to measure nutritional quality of foods is an ongoing process. In this study, we attempt to classify WEF based on their nutritional composition using hierarchical cluster analysis (HLA), principal component analysis (PCA) techniques and discriminant analysis followed by their nutrient profile density. Both HLA and PCA are two multivariate analysis techniques that ease interpretability of results and are usually used to reduce data sets by clustering group cases into homogeneous groups. Nutrient density profiling on the other hand is a new concept that has evolved in recent years and is recognised by the World Health Organisation for ranking individual foods based on their nutrient composition as either more or less nutritious [7]. The nutrient concentration in a food is then compared to the recommended concentration of a given nutrient in a healthful diet. Using the food composition data base, Rampersaud (2007) was able to classify 100% fruit juices of apple, grape, pink grapefruit, white grapefruit, orange, pineapple, and prune by their nutrient density using six methods including nutrient for calorie, calorie for nutrient, ratio of recommended to restricted (RRR) nutrient, nutrient for calorie. Pink grapefruits were found to contain the highest nutrient density score with this ranking being fairly consistent. In another study, citrus fruits and juices, milk, fortified ready-to-eat cereals, eggs, potatoes, and legumes and beans were found to be nutrient rich foods by using the Nutrient Rich Foods Index ranking method. Furthermore, the French national food composition database classified 637 foods from the French national food composition database using the nutrient adequacy score. This classification had fruits and vegetables registering the higher scores. Although these nutritional ranking methods have been used to promote consumption of food groups in developed countries, none of these methods have been use to classify WEFs. Moreover, the shortcoming of these methods are that it they difficult to determine which species within a food group are the most nutritious.

WEF have been regarded as a nutritious food group because of their richness in nutrients like vitamins and minerals, but not all them have the same nutritional value, and selecting the specific nutritious species have been difficult. Therefore, the potential application of classification WEF based on their nutrient content and identifying species that are more nutrient rich for consumer education and dietary guidance for better nutrition and health of the most vulnerable groups of the population suffering from malnutrition in developing countries remains wanting. The objective of this study is to classify WEF based on their nutritional composition. In the context of this study, nutrient rich WEF can be regarded as those that can provide more nutrients.

Materials and Methods

Study area and study fruits selection

The study was conducted in the Teso subregion of eastern Uganda. Teso sub region lies within the dryland socio-ecological production landscape [10] stretching from Southwestern to North-eastern Uganda. A socioeconomic survey earlier conducted showed that this region is rich in WEF [11]. This study therefore focused on community preferred species; *Carissa spinarum* L, *Saba comorensis* (Bojer ex A. DC.) Pichon, *Sclerocarya birrea* (A. Rich.) Hochst., *Flacourtia indica* (Burm. f.) Merr, *Vitex doniana* Sweet, *Strychnos spinosa* Lam., *Ximenia americana* L., *Vangueria infausta* Burch, *Vitellaria paradoxa paradoxa* C.F. Gaertn. and *Physalis minima* L. (Table 1). For the purpose of future reference, these WEF were collected from Omodoi and Orungo sub counties in Katakwi (1.9142° N, 33.9583° E) and Amuria (2.0302° N, 33.6428° E) districts.

Family	Species	Common name	Local name (Ateso dialect)	Description	Type	Taste	Colour when ripe
Apocynaceae	*C.spinarum/*	Arabic/simple spine num num	Aimuria/Eimuriei	Shrub	Berry	Sweet and sweet sour	Dark red, purple and purplish black
	Sabacomorensis	Rubber vine	Emago	Liana	Berry	Sweet sour	Orange Yellow
Anacardiaceae	*S.birrea*	Marula	Ejjikai/Ekajikaji	Tree	Plum	Sour sweet	Light yellow green
Flacourtiaceae/ Salicaceae	*Fl indica*	Governor	Elepulepu/	Shrub/ Tree	Berry/ Plum	Sour	Reddish black to Purple
Lamiacea/ Verbanaceae	*V. doniana*	Black plum	Ekarukei/Ewelo	Tree	Berry/ Plum	Sweet	Purplish to black
Loganiacea/ Strchynaceae	*S. spinosa*	Monkey orange	Eturukuku/Eturukukut	Tree	Fruit	Sweet-sour	Yellow
Olacaceae	*X. americana*	Yellow plum or tallow plum or wild plum, blue soar	Ekwalikwal/Elamai/Ailama	Shrub	Plum	Sweet-sour	Yellow Orange or red
Rubiaceae	*V. infausta*	Wild-medler	Emuleru	Shrub	Plum	Sweet	Greenish
Sapotaceae	*Vi paradoxa*	Shea	Ekungur	Tree	Plum	Sweet	Green
Solanaceae	*P. minima* L.	Sunberry	Etagoli/Acin Aidodok	Herb	Berry	Sweet sour	Yellow

Table 1: List and description of ten study wild edible fruits of Teso sub region, Uganda.

Collection and processing of fruit samples

To facilitate timely collection of ripe fruits, field assistants were recruited from local communities and trained to monitor the phenology of selected fruit trees. Once the fruits ripened, between 10-50 kg of each fruit type were collected by picking from each target species depending on their availability. The fruits were transported in cooler boxes and stored under cold conditions (-20°C) at the Natural Chemotherapeutics Research Institute (NCRI) laboratory until they were de-pulped and analysed.

The frozen fruits were de-frosted under room temperature and sorted to remove over ripe and damaged fruits. They were washed with tap water, and depending on the type, de-pulped either by cutting with a stainless-steel knife to remove the pulp or mashing in a pan with a wooden stick. The pulp was blended and divided into two portions. One portion was used for chemical analysis while the other was dried for proximate and mineral composition analysis. A sample of the freshly extracted pulp (100-200g) for each fruit type was placed in an aluminium foil and dried in a vacuum oven at 50-60°C for 12 hours. The dry pulp was ground into powder or to paste, placed in a dry plastic airtight container and stored at room temperature in a laboratory locker for chemical analysis.

Chemical and proximate analyses

The wet portion of the pulp was used for analyses of moisture, pH, total soluble solids, titratable acidity and vitamin C using standard methods as described in AOAC (1999) [12]. The dry pulp on the other hand was analysed for crude protein, crude fat, dietary fibre, total carbohydrates, total ash and caloric value using standard methods in AOAC (1999). Total carbohydrates were determined by difference [13].

Mineral analysis

Mineral composition analyses for selected minerals important in nutrition were conducted using dry pulp in an Atomic Absorption Spectrophotometer model AA-63000 with a graphite furnace

[14]. To perform the experiment, two (2.0) g of dry fruit pulp powder or paste were weighed and placed in a clean boiling tube. Distilled water (5.0 ml) and concentrated nitric acid (25 ml) were added and mixed by shaking gently. The mixture was then refluxed over a water bath at 90°C for 4 hours, cooled and 10 ml of concentrated perchloric acid added. The tubes were again refluxed over a water bath at the same temperature for one hour and later cooled to room temperature. Concentrated hydrochloric acid (2.0 ml) was added to the sample, made to 100 ml with distilled water and filtered. Standard solutions of different selected minerals were prepared in the concentrations of 0.125, 0.25, 0.50, 1.00 ppm for development of calibration curves for their analyses.

Data analysis

Data were analysed to determine the means and standard deviations of the nutritional values of each fruit. One-way Analysis of Variance was performed with IBM SPSS statistics version 22 to test for significance in differences of their mean values, and also compared using Duncan's means test (P < 0.05). Principal component analysis (PCA) and hierarchical cluster analysis (HLA) were conducted using IBM SPSS statistics version 22 to establish homogeneity in the nutritional values. The PCA was used to reduce large nutritional composition data set of correlated variables to a relatively smaller number of components and also show relationship among them. The benefit of hierarchical clustering on the other hand in this study is that clusters remain the same irrespective of the order in which the data are presented. A dendrogram was then generated to examine the feasible range of mean values for the number of clusters present. General discriminant analysis (GDA) was applied to determine whether a given cluster was an appropriate one and identify the proximate parameters that contributed most to the clustering. Therefore, each WEF assigned to a given group was computed to maximize the classification to test clustering. To avoid the risk of overfitting, the number of variables for GDA were reduced, considering only the signal which presented a factorial weight during PCA > |0.7|. After the construction of the model, to evaluate the classification performance, the leave-one out method was used as a validation procedure.

Nutrient density profiling was used to evaluate the nutritional value of WEF using the Nutrient Food Index (NFI). This is a method that is robust, versatile, and statistically validated. (Rampasaud, 2007; Bianchi., *et al*. 2020) and is used to rank individual foods, meals or diets based on their nutritional desirability consistent with dietary guidelines [17]. The model considers seven desirable food components (DFC) (i.e., Ca, Fe, Zn, fibre, Mg, K and vitamin C); and two non-desirable food components (NDFC), (i.e., fat and Na). The nutrients Ca, Fe, Zn and fibre were weighted by coefficient 0.114; Mg, K and vitamin C by coefficient 0.057 and fat and Na nutrients by the coefficients 0.31 and 0.13 respectively. Weighting of nutrients in food is important because it helps make discrimination based on nutrient biological quality and bioavailability, and their individual contribution in the final score (Bianchi., *et al*. 2020). Micronutrients that were not included in the calculation were assumed to be "0" (Jomaa., *et al*. 2016). The index of a given WEF was calculated on micro soft excel spread sheet according to the formula

$$\text{NFI} = \sum \frac{\text{DFC}}{\text{REC}_i} - \sum \frac{\text{NDFC}_{iwi}}{\text{REC}_j}$$

where DFC*i* and NDFC*j* refer to the amount of the corresponding nutrient in a recommended serving size of the fruit, wi_j are the weights and $RECi_j$ refers to the daily recommendations of intake of the nutrient. Reference DVs based on a 2000-kcal diet were obtained for protein (50g); fiber (25g); vitamins A (5000 IU), C (60 mg), and E (30 IU); calcium (1000 mg); iron (18 mg); potassium (3500 mg); and magnesium (400 mg) [17].

Since there was a need to position the fruits relative to one another, nutrient profile scores were partitioned into quintiles in micro soft excel.

Results

Chemical characteristics

The chemical characteristics (pH, titratable acidity and total dissolved solids) of the pulps are provided in Table 2. The fruits that had the highest and lowest pH values were *P. minima* (5.82 ± 0.04) and *X. americana* (2.97 ± 0.04) respectively. *X. americana* (29.32 ± 1.64%) fruits on the other hand also registered the highest titratable acidity (TA) while *S. commorensis* (15.50 ± 0.00° had the highest total soluble solids (TSS). The highest TSS/TA ratio was exhibited by *P. minima* (4.49). One-way analysis of variance showed no significant differences (P ≤ 0.05) in the pH mean values of *X. americana, C. spinarum* and *S. comorensis*. Similarly, no significance differences (P ≤ 0.05) in TA were exhibited among *S. spinosa, V. paradoxa, V. infausta* and *C. spinarum*; while *S. comorensis* and *C. spinarum* fruits did not show significant difference (P ≤ 0.05) in TSS (Table 2).

Proximate composition

The proximate composition of WEF pulps is presented in Table 3. Generally, the fruits with the highest moisture, protein and vitamin C were *C. spinarum* (94.55 ± 0.2 %), *V. infausta* (10.98 ± 0.25g/100g), *S. birrea* (93.75 ± 44.19mg/100g) respectively. However, fruit that had the highest dietary fibre, total carbohydrates, total energy were; *P. minima* (52.55 ± 0.15g/100g), *F. indica* (31.22

Fruit	Ph	Titratable acidity (%)	TSS (°B)	TSS/TA ratio
C. spinarum	3.30 ± 0.02^{ab}	4.12 ± 1.71^{a}	15.27 ± 1.25^{h}	3.71
S. spinose	4.44 ± 1.54c	2.56 ± 0.00^{a}	8.25 ± 0.75^{b}	3.22
S. comorensis	3.00 ± 0.05^{a}	17.02 ± 2.34^{d}	15.50 ± 0.00^{h}	0.91
F. indica	4.05 ± 0.13^{bc}	7.56 ± 1.35^{bc}	10.13 ± 0.11^{de}	1.34
V. paradoxa	4.77 ± 0.19^{c}	3.02 ± 0.50^{a}	13.50 ± 0.00^{g}	4.47
X. americana	2.97 ± 0.04^{a}	29.32 ± 1.64^{e}	10.77 ± 0.25^{e}	0.37
P. minima	5.82 ± 0.04^{d}	2.13 ± 0.01^{a}	9.57 ± 0.15^{cd}	4.49
V. infausta	4.09 ± 0.06^{bc}	1.60 ± 0.25^{a}	3.03 ± 0.06^{a}	1.89
V. doniana.	4.19 ± 0.04^{bc}	4.47 ± 1.56^{ab}	12.00 ± 1.50^{f}	2.68
S. birrea	4.50 ± 0.06^{c}	10.35 ± 2.21^{c}	8.43 ± 0.06^{bc}	0.81

Table 2: Titratable acidity, pH and TSS for ten selected wild fruit pulps.

± 3.01 g/100g) and S. *comorensis* (156.18 ± 10.50 Kcal), respectively. One-way analysis of variance showed no significant difference ($P \leq 0.05$) in the moisture content between *C. spinarum* and *P. minima*; dietary fibre between *F. indica* and *P. minima* and total carbohydrate between *S. spinosa* and *V. doniana*. There were also no significant differences ($P \leq 0.05$) in total energy among *S. spinosa, V. doniana* and *V. infausta* samples, and vitamin C among the samples of *S. birrea, S. comorensis* and *F. indica* (Table 3).

Mineral composition

The mineral compositions are presented in Table 4. The fruits that had the highest mean values for K, Na, Ca, Mg, Fe and Zn were *V. infausta* (2525.10 ± 38.89), *F. indica (*72.73 ± 3.80), *S. spinosa* (55.40 ± 2.14mg/100g), *V. doniana (*83.20 ± 0.66*), S. comorensis* (15.07 ± 0.47mg/100g), and *S. comorensis* (3.17 ± 0.06 mg/100g) respectively. One way analysis of variance showed no significant difference ($P \leq 0.05$) in the mean values of K for *X. americana* and

Fruit	Moisture content (%)	Total fat content (g/100g)	Crude protein (g/100g)	Dietary fibre (g/100g)	Total carbohydrate (g/100g)	Total energy (Kcal)	Vitamin C (mg/100g)
C. spinarum	94.55 ± 0.2^{e}	1.77 ± 0.27^{b}	2.32 ± 0.96^{a}	25.75 ± 0.88^{b}	1.36 ± 0.48^{a}	30.65 ± 0.49^{a}	52.08 ± 14.73^{b}
S. spinosa	63.00 ± 9.99^{a}	0.66 ± 0.0^{9}a	5.94 ± 0.25^{c}	25.10 ± 2.23^{b}	30.40 ± 10.24^{c}	151.31 ± 39.16^{e}	6.52 ± 1.1^{8}a
S. comorensis	62.21 ± 2.83^{a}	0.84 ± 0.16^{a}	5.95 ± 0.02^{c}	26.21 ± 1.19^{b}	31.22 ± 3.01^{c}	156.18 ± 10.50^{e}	62.50 ± 0.00^{bc}
F. indica.	84.00 ± 1.41^{cd}	3.01 ± 0.56^{c}	3.41 ± 0.22^{b}	51.62 ± 0.17^{g}	9.59 ± 1.0^{7a}b	79.83 ± 8.45^{d}	62.48 ± 0.00^{bc}
V. paradoxa	74.00 ± 0.99^{bc}	2.67 ± 0.04^{c}	6.75 ± 0.04^{cd}	38.82 ± 0.56^{e}	16.58 ± 0.91^{b}	117.45 ± 4.17^{cd}	7.03 ± 1.10^{a}
*X.*americana	79.50 ± 2.55^{cd}	1.61 ± 0.07^{b}	9.56 ± 0.17^{g}	29.24 ± 0.74^{c}	9.33 ± 2.78^{ab}	90.05 ± 9.83^{a}	33.33 ± 11.78^{ab}
P. minima	87.01 ± 1.41^{de}	4.20 ± 0.14^{d}	6.67 ± 0.13^{d}	52.55 ± 0.1^{5}g	2.13 ± 1.68^{a}	73.00 ± 4.95^{b}	33.30 ± 9.79^{ab}
V. infausta	73.50 ± 2.12^{bc}	6.73 ± 0.58^{e}	10.98 ± 0.2^{5}f	46.33 ± 1.03^{f}	8.80 ± 1.3^{0a}b	139.65 ± 11.38^{de}	28.12 ± 4.42^{ab}
V. doniana.	70.15 ± 0.63^{ab}	0.78 ± 0.15^{a}	2.50 ± 0.06^{a}	35.39 ± 1.07^{d}	26.58 ± 0.4^{3}c	123.28 ± 3.29^{cde}	11.93 ± 0.81^{a}
*S. birre*a	85.00 ± 1.41^{d}	1.92 ± 0.29^{b}	7.92 ± 0.04^{e}	19.73 ± 0.7^{1}a	5.17 ± 1.09^{a}	69.58 ± 7.11^{b}	93.75 ± 44.^{1}9c

Table 3: Proximate composition of selected wild fruit pulps.

Different letters in the column indicate significant differences ($P \leq 0.05$) by Duncan's means test.

V. infausta; Mg values for *X. americana* and *P. minima*; and Ca values for *S. birrea and C. spinarum;* Fe values for *C. spinarum*, *S.* spinosa and *V. paradoxa*; and Zn values for *C. spinarum* and *V. paradoxa* (Table 4).

WEF nutrient recommended dietary allowance (RDA) contributions

The RDA nutrition contributions of the different WEF is presented in figure 1. Dietary fibre registered the highest nutritional contribution in WEF with *P. minima* (210%) having the highest val-

WEF	Na	K	Mg	Fe	Ca	Zn
C. spinarum	12.13 ± 1.30^{c}	1888.00 ± 44.91^{e}	23.73 ± 0.29^{bc}	7.43 ± 1.62^{d}	14.47 ± 0.15^{d}	0.57 ± 0.06^{cd}
S. spinosa.	24.87 ± 0.3^{2}d	1334.20 ± 25.46^{b}	24.90 ± 0.00^{d}	7.03 ± 1.00^{cd}	55.40 ± 2.1^{4}g	0.17 ± 0.06^{a}
S. comorensis	7.33 ± 0.12^{ab}	1682.10 ± 59.41^{d}	23.03 ± 0.31^{b}	15.07 ± 0.4^{7}f	20.40 ± 0.44^{e}	3.17 ± 0.0^{6}h
F. indica	72.73 ± 3.80^{e}	1065.20 ± 8.99^{a}	61.83 ± 1.33^{e}	5.03 ± 0.09^{abc}	8.27 ± 0.15^{c}	1.87 ± 0.06^{g}
V. paradoxa	7.33 ± 0.11^{ab}	1554.60 ± 53.17^{c}	25.17 ± 0.06^{d}	5.80 ± 0.26^{bcd}	41.03 ± 1.36^{f}	0.60 ± 0.00^{d}
X. americana.	5.73 ± 0.12^{a}	2035.00 ± 44.91^{f}	18.03 ± 0.12^{a}	9.97 ± 1.37^{e}	5.00 ± 0.10^{ab}	0.83 ± 0.06^{e}
P. minima	8.30 ± 0.43^{b}	1045.00 ± 66.29^{a}	18.90 ± 0.17^{a}	4.43 ± 2.84^{ab}	3.77 ± 0.15^{a}	1.07 ± 0.06^{f}
V. infausta	11.67 ± 0.12^{c}	2058.83 ± 30.31^{f}	24.86 ± 0.89^{d}	3.73 ± 0.06^{ab}	5.53 ± 0.21^{b}	0.50 ± 0.00^{c}
V. doniana.	8.93 ± 0.12^{b}	1554.60 ± 53.17^{c}	83.20 ± 0.6^{6}f	3.47 ± 0.06^{a}	8.40 ± 0.20^{c}	0.30 ± 0.00^{b}
S. birrea	8.57 ± 0.15^{b}	2525.10 ± 38.8^{9}g	24.27 ± 0.11^{cd}	3.31 ± 0.67^{a}	15.60 ± 0.72^{d}	1.07 ± 0.06^{f}

Table 4: Mineral composition of selected wild fruit pulps (mg/100g).

ue followed by *F. indica* (206%). Generally, dietary fibre in the WEF had RDA contributions of over 100%, except for *S. birrea*. Vitamin C, iron and potassium also made significant RDA contributions with S. *birrea* (72%), *S. comorensis* (84%) and *S. birrea* (72%) respectively (Figure 1).

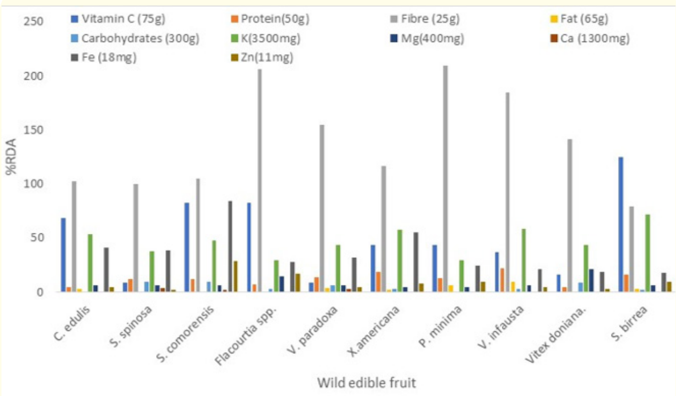

Figure 1: Recommended Dietary Allowance (RDA) contribution of the different nutrients in the ten wild edible fruits.

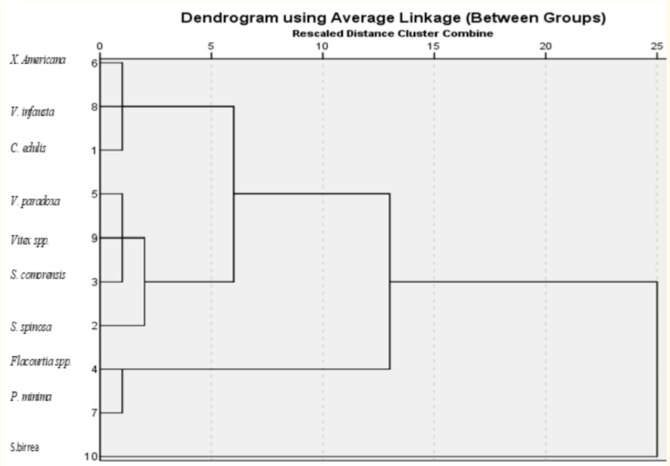

Figure 2: Dendrogram depicting agglomerative hierarchical clustering of 10 wild edible fruits.

Principal component (PC) 1, PC2, PC3, PC4 and PC5 each accounted for 27.48%, 21.99%, 17.46%, 11.84 and 7.51% of the variations respectively (Table 5).

In the PC factor loadings, moisture content, total energy and total carbohydrates explained the variability of wild edible fruits in PC 1; Zn, Fe and TA explained variability in PC 2; Fat and TSS explained variability in PC 3, Dietary fibre and K explained variability in PC 4; and Mg explained variability in PC 5 (Table 6 and Figure 3).

Principal component analysis

The hierarchical dendrogram clustering separated *S. birrea* from the other nine WEFs at linkage distance of 25 while the linkage distance of 13 separated *F. indica* and *P. minima* from the others. Within the remaining cluster, *X. americana*, *V. infausta*, and *C. spinarum* was separated from the others at the linkage distance of approximately 6 (Figure 2).

The principal component analysis presented five components with eigenvalue >1.0 that accounted for 86.27% of the variability in their nutritional composition values of the ten wild edible fruits.

Discriminant analysis

The discriminate analysis model was able to separate three clusters of WEF i.e., cluster 1 (X. *americana, V. infausta, and C. spinarum*), Cluster 2 (*V. paradoxa, V. doniana, S. comorensis* and *S. spinosa*) and cluster 3 (*F. indica and P. minima*). Cluster 4 did not have

Principal Component	Eigenvalue	Differences between eigenvalues	% Variation explained	Cumulative % variation
1	4.40	0.88	27.48	27.48
2	3.52	0.73	21.99	49.47
3	2.79	0.89	17.46	66.93
4	1.90	0.70	11.84	78.77
5	1.20	0.26	7.51	86.28

Table 5: Eigenvalues of the Principal Components of the correlation matrix for 10 WEF.

Variable	Explained variance				
	PC1	PC2	PC3	PC4	PC5
pH	-0.090	-0.662	0.195	0.485	-0.14.6
TA	-0.011	0.738	-0.016	-0.414	-0.083
TSS	-0.074	0.326	-0.862	0.052	-0.073
Moisture	-0.985	-0.118	-0.025	0.049	-0.012
Total fat content	-0.253	-0.168	0.829	0.326	-0.127
Crude protein	0.140	0.108	0.781	-0.255	-0.502
Dietary fibre	-0.135	-0.133	0.474	0.786	0.210
Total carbohydrate	0.921	0.114	-0.310	-0.035	0.157
Total energy	0.963	0.090	0.215	0.028	-0.015
Vitamin C	-0.569	0.552	0.021	-0.190	0.093
Na	-0.104	0.136	0.004	0.513	0.574
K	-0.202	0.120	0.238	-0.889	-0.160
Mg	0.126	-0.155	-0.145	0.109	0.937
Fe	0.322	0.772	-0.363	-0.047	-0.345
Ca	0.582	-0.329	-0.424	0.011	-0.344
Zn	0.032	0.880	-0.093	0.293	-0.002

Table 6: Explained variance of the five PC from the Principal Component analysis of 10 wild fruit variables.

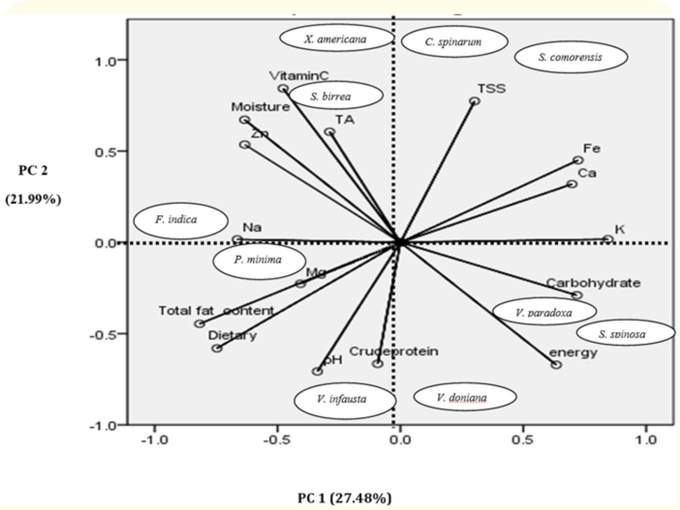

Figure 3: Biplot obtained from the PCA illustrating separation of the ten wild edible fruits.

enough cases and therefore was not included in the model. Canonical Discriminant Analysis (CDA) generated three Canonical Discriminant Functions (CDF) of which only the first one was relevant and sufficient to explain 99.2% of the total variation of the three clusters. Among the variables selected based on their PCA (>0.70) for separation between clusters of WEFs, total carbohydrates and potassium were the major contributors of variation (Wilks' lambda; potassium 0.041 and carbohydrates 0.173). CDF1 was responsible for the separation of the cluster 1 from cluster 2 while CDF1 in combination with CDF2 separated cluster 3.

The contribution of each variable to a CDF can be evaluated through the standardized coefficients; while the degree to which each variable is related to the CDF can be better assessed by the structure coefficient (Cama-Moncunill., *et al*. 2021). TSS and dietary fibre were the most important variables for differentiating WEFs. However, moisture content and potassium influenced the model (CDF1) in a negative direction, indicating that their high proportions were associated with WEF in the clusters (Table 7).

Nutrient density profiling

This study established the nutrient profile scores for 10 WEF based on their nutritional composition (Table 5). The NFI model had *F. indica* (0.798 score) with highest score as the most nutrient desirable fruit while *S. birrea* (0.281) fruit had the lowest score. The fruits with favorable NFI scores included *V. infausta* (0.590), *V. paradoxa* (0.589) and *V. doniana* (0.588). The quintile ranking of the NFI scores, *F. indica* and *P. minima* were in the fifth quintile and *S. birrea* and *C. spinarum* in the first quintile. The fruits that were in the intermediate third quintiles were *V. doniana* and *X. americana*in (Table 8).

The relationship between nutrient profile scores and energy of fruits was plotted on scatter plots. The plot had *F. indica* and *P. minima* discriminated from other WEF. Similarly, there was also a negative correlation in NFI scores to energy for *F. indica* and *P. minima* (Figure 4).

Variable	*LD1 (0.992)	LD2 (0.008)	LD3 (0.000)
Titratable acidity	0.465	1.465	0.353
TSS	9.118	-1.644	0.839
Moisture content	-7.006	1.851	-0.267
Crude protein	-.264	-.119	0.348
Dietary fibre	6.576	.528	0.714
Potassium	-6.183	-.256	0.182

Table 7: Standardized canonical discriminant function coefficients of WEF nutritional values.

*Linear Dimension.

Wild Fruit	Nutrient profile	Quintile rank
NFI	**NFI**	1
C. spinarum	0.390	2
S. spinosa	0.415	2
S. comorensis	0.428	5
F. indica	0.798	4
V. paradoxa	0.589	3
X. americana.	0.456	5
P. minima	0.777	4
V. infausta	0.590	3
V. doniana.	0.588	1
S. birrea	0.281	

Table 8: Nutritional density profile of wild fruits and their relative ranking.

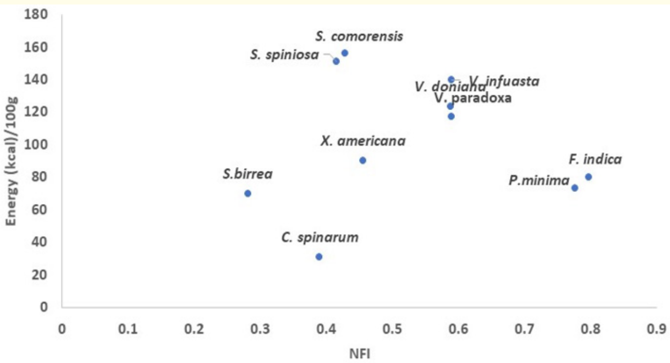

Figure 4: Scatterplot showing the relationship between energy content and NFI scores.

Discussion

Understanding WEF based on their nutritional value or quality is crucial for nutritional public health education and dietary guidance of the population. It is clear from this study that there were WEF with both non-significant and significant differences ($p \leq 0.05$) in nutrient contents. Since there is considerable observed variation in the nutrient content, the RDA of the different nutrients was determined to assess the nutritional potential of each WEF. Generally, the RDA showed that all the WEF registered exceptionally high dietary fibre, and some fruits (e.g. *S. birrea, F. indica, S. comorensis* and *C. spinarum*) had remarkably high vitamin C, iron, and potassium with over 50% contribution per 100g of pulp. Based on this background, the study then clustered WEF into four groups based on their nutritional composition. In the classification, *S. birrea* fruit was singly discriminated from other nine fruits by their vitamin C and Zn while the second cluster of *F. indica* and *P. minima* were discriminated from other clusters by their dietary fibre, Na and total fat. The other WEF clusters comprising of *V. paradoxa, V. doniana, S. comorensis* and *S. spinosa* were discriminated from others by their total carbohydrates, Fe, Ca and K. On the other hand, *V. infausta, X. americana* and *C. spinarum* were discriminated by their crude protein and energy (Figure 3). Furthermore, the dendrogram classification exhibited a significant correlation with the PCA that accounted for 86.27% of the variability of the nutrient composition. The CDA had the first CDF being sufficient to explain 99.2% of the total variation of the three clusters with, total carbohydrates and potassium nutrients being the major contributors of variation.

Therefore, the concept of nutrient density that has previously been validated became a valuable tool for further ranking WEF based on their overall nutritional value. According to Drewnowski [18], nutrient density is the ratio of the nutrient composition of a food to the nutrient requirements of the human. A scoring system to compare the nutritional profile of WEF using NFI model then found *F. indica* and *P. minima* in the upper quintile, and their overall nutritional values were largely contributed by the key nutrients including protein, potassium and dietary fibre (Table 7). While dietary fibre were high in these fruits, their protein content and potassium were considerably low. Since nutrient-dense foods are often described as those that contain more nutrients than calories (Drewnowski, 2010) [19], WEFs like *F. indica,* and *P. minima* can in this case be regarded as high dietary fibre dense fruits with substantial amounts for promotion in nutritional public health education.

Limitations of the Study

The nutritional composition data was based on the fruits samples collected. Since variability of nutrient value can occur for the same fruits, the classification may change. Furthermore, the calculations used for the nutrient profile were based on only those nutrients determined in this study. Nutrients that were not analysed in the sample, but appear in profiling calculations formulae, were considered to have zero values, and this could have affected the scores. It was also not possible to include phytochemicals in the nutrient profile calculation, since the data was not available. Although saturated fat is a key marker in nutrient desirability, the calculation was instead based on total fat. We suggest that these limitations should be included in subsequent nutrient profile studies. Combining nutrient profiling, food prices, and the knowledge of people's wild fruit eating habits be considered in future studies.

Conclusion

This study is the first step we are taking to classify WEF based on their nutritional value. In this classification, the PCA revealed that moisture, total carbohydrates and energy in PC 1, and Zn, Fe, TA and vitamin C in PC 2 contribute to their variability. Nutrient profiling ranked d *F. indica*, *P. minima* as the most nutrient desirable fruits. Therefore, these fruits should be promoted in communities for public health nutrition, and plant breeders should domesticate these fruit plants.

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Conflict of Interest

There is no conflict of interest.

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