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Proximate composition of wild and on-farm *Tamarindus indica* LINN fruits in the agro-ecological zones of Uganda

Abstract

Proximate composition of wild and on-farm *Tamarindus indica* Linn fruits (pulp and seeds) were evaluated from three agro-ecological zones and land use types in Uganda. The study objectives were: to compare the proximate composition of *T. indica* pulp and seeds among agro-ecological zones and land use types, and to determine the relationships between the pulp and seeds proximate composition variables among the agro-ecological zones and land use types in Uganda. Samples were analysed using standard procedures for moisture content, total ash, crude protein, crude fibre, crude oil and total carbohydrates. The results show that there were significant differences (P<0.05) in the pulp and seeds proximate variables between agro-ecological zones except the seed ash content that showed significant difference between land use types. Only total ash contents showed significant interactions between agro-ecological zones and land use types while samples from the Lake Victoria Crescent agro-ecological zone were rich in proximate contents than other zones. The proximate composition revealed the presence of pulp and seed samples for: moisture content (27.40-31.60; 9.00-13.90%), total ash (4.60-5.00; 2.20-2.40%), crude protein (15.70-16.10; 4.30-4.50%), crude fibre (7.10-8.40; 8.00-9.00%), crude oil (0.27-0.29; 2.64-2.98%) and total carbohydrates (50.20-56.20; 56.20-61.00%) respectively. There were no significant relationships among the proximate variables with agro-ecological zones and land use types. Both pulp and seeds showed good proximate contents, but the traditionally inedible seeds (thrown away after depulping) have more prospects and are recommended for consumption due to the high proximate contents than pulp, but first need to be processed before incorporation into human and animal diets.

Keywords: agro-ecological zones, land use types, proximate, *Tamarindus indica,* on-farm, Uganda

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Introduction

Wild edible plants are known to make important contributions to food baskets and livelihoods in the smallholder and subsistence farming communities of sub-Saharan Africa.[1] The legumes, many of which are wild and indigenous plants, are major sources of plant protein, fats and essential amino acids[2] and the nutritional values of legumes are of great importance.[3] The nutritional values of indigenous fruit bearing tree species show that many are rich in phytochemicals, which include glucosides, essential vitamins and minerals while some are high in fat, protein and crude fibre.[4] According to Pereira et al.,[5] non-conventional fruits and vegetables can be richer in fibre and compounds with antioxidant functions than conventional foods. Food composition data are extremely important for the development of food composition tables, consumption of balanced nutrients, assessment of the supply and food consumption of a country.[6] In addition, verification of the nutritional adequacy of the diets of individuals and populations, evaluation of nutritional status, and development of research regarding the relations between diet and disease, agricultural planning, and food industry introduction.[6]

The proximate and nutrient analyses of edible plants and vegetables play a crucial role in assessing their nutritional significance.[7] Lipids, proteins and carbohydrates constitute the principal structural components of foods.[8] Carbohydrates are one of the main types of nutrients and the most important source of energy for most organisms, including humans. Moisture content is among the most vital and mostly used measurement in processing, preservation and storage of food.[9] Proteins are organic compounds made up of 20 common amino acids, 9 of them are considered essential because the body can not make them and they must be supplied by eating healthy. Ash is an inorganic residue remaining after either ignition or complete oxidation of organic matter in a foodstuff.[10] Yusuf et al.,[11] reported that the total ash content, which is an indicator of mineral contents, is lower in *T. indica* pulp than in seeds, showing that the seed contains relatively large amounts of proximate composition and some other mineral elements than the pulp. Also, ash content of most fresh foods rarely is greater than 5%, pure oils and fats generally contain little or no ash. According to Marshall,[10] fats, oils and shortenings vary from 0.0-4.1% ash, and dried fruits are higher (2.4-3.5%).

Tamarindus indica LINN (syn. *Tamarindus occidentalis* Gaertn.; *Tamarindus officinalis* Hook.), belongs to the dicotyledonous family Leguminosae, sub-family Caesalpinioideae, which is the third largest family of flowering plants.[12] It is a monotypic taxon, containing the sole species *Tamarindus indica*.[13] The species is a native of Uganda and Africa, and has multipurpose uses that is domesticated and widely distributed as wild plant.[14] It is commonly found near homesteads, on-farms, along roadsides, market places, in many public places and also grows in neglected places (such as swamps and invaded by anthills) where they are extensively used by smallholder farmers.[14,15]

The *T. indica* fruit is economically important to the population due to its ability to provide the household with incomes when sold in the local markets, local juice (sweet and sour taste), timber and fodder. According to Okello et al.[15] the species is used as an agroforestry and shade tree, cures many ailments (example, meningitis) and flowers are good for bee forage. The species is also a valuable source of food especially the pulp, which are eaten by many local communities as well as used for making local millet bread and porridge, and local beverages.[15] Many communities in Uganda do not attach much cultural beliefs toward this native tree species.

Although *T. indica* is an indigenous fruit tree in Uganda, it has been neglected as a potential food source, remaining little unknown, under-utilized and limiting its potential variety in the diets of the rural poor population. The majority of the species' products are still being gathered from the wild population with no deliberate attempts to domesticate it, due to lack of and inadequate incentives for farmers to cultivate them. However, its utilization as famine food clearly reduces the over-dependence on other indigenous plants, legumes, vegetables and fruits and goes a long way to alleviate poverty and household nutrition requirements. There is also an increasing domestic demand for *T. indica* fruits, providing an excellent scope for the extension of its cultivation, protection and conservation. In addition, there is lack of scientific work for the AEZs' land uses of Uganda, and potential benefits that knowledge regarding the proximate composition of fruits can offer to human health, economic, social and cultural benefits. Thus, the objectives of this study were: to compare the proximate composition of *T. indica* pulp and seeds among the agro-ecological zones and land use types, and to determine the relationships between the *T. indica* pulp and seeds proximate composition among the AEZs and land use types of Uganda. The study also tested if there were no significant differences in *T. indica* pulp and seeds proximate composition between AEZs and land use types. The proximate variable is an important step in determining the quality of *T. indica* raw materials and often the basis for establishing the nutritional values and overall product acceptance by the consumers.

Materials and methods

Description of agro-ecological zones of Uganda

Uganda is a landlocked country with an area of 241,551 km^2 located astride the Equator in Eastern Africa region and lies between latitude 1°30' South and 4° North and longitude 29°30' East and 35° West. The country has unique biodiversity due to its distinctive biogeographical location - 7 of the 18 (39%) of plant kingdoms in Africa exist in Uganda. The type and character of the soils of Uganda are defined by a number of parameters such as the nature of the parent rock, age of the form and climate, especially the amount of moisture.[13] The climate is tropical, with distinct wet and dry seasons while the dry season occurs between December and March. There are nine AEZs based on agro-climatic factors (rainfall totals and distribution) and soils (productivity and fertility). Topography, temperatures, moisture, and vegetation cover are the secondary factors considered uniform in each AEZ but differing between AEZs.[16,17] In each AEZ, there are fairly homogenous climate, landform and soils, land cover, specific range of opportunities and constraints for land use but differ between AEZs.

Study areas

The present study on *T. indica* was conducted in the three different AEZs of Uganda where *T. indica* trees are grown in fairly large number, both on-farm and on wild land use types. Each of the three selected AEZ was represented by one district: Lake Victoria Crescent, Nakasongola district; West Nile, Moyo district and Eastern, Soroti district (Figure 1).

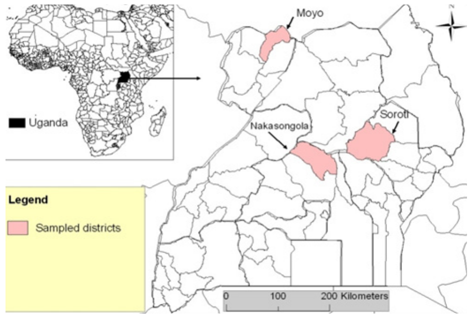

Figure 1 Map of Uganda showing Sampled Districts.

Nakasongola district is found in the Lake Victoria Crescent AEZ. It covers an area of 3,510 km^2 and altitude ranges from 1,000 to 1,400 masl. The vegetation type is open deciduous savanna woodland growing on *Bululi* and *Lwampanga* soil types made from basement complex formations of the pre-cambrian age. The district is represented under the Buganda-Toro System geological formation. Large tracts of the system are granitized but also occur low grade phyllites and with tropical climate. There are two rainy seasons (March to July and August to November), with bimodal total rainfall of between 875-1,000 mm per annum. Minimum and maximum temperatures are 18 and 28°C respectively.[18]

Soroti district is located in Eastern AEZ which covers an area of 3,374 km^2. The altitude varies from 1,036 to 1,127 masl. The vegetation types are wooded savanna, grassland savanna, forests and riparian. The major soil types are Serere and Amuria catena, Metu complex and Usuk series of moderate agricultural productivity. Its major geological formation is granites, mignalites, gneiss, schists and quartzites. The underlain rocks of the basement complex precambrian age includes granite, mignalite, gneiss, schists and quartzite. The area's tropical savanna climate has two rainy seasons, from March to June and August to November with rainfall ranging from 1,000-1,500 mm, the minimum and maximum temperatures are 18 and 31.3°C respectively.[19] Moyo district is found in the West Nile AEZ, covers an area of 1,891 km^2 and the altitude ranges from 600-1,586 masl. There are three main categories of geological formations; gneiss, alluvial deposits, and schist, quartzite and marble. While the major soil types are; vertisols, leptosols, alluvial deposits and ferrasols whose agricultural productivity are moderately fertile.[20] Rainfall varies from 1,500 to 1,700 mm in less pronounced bimodal mainly in March to June and August to November while late November to early March is a dry season. The minimum (23.7°C) and maximum (30°C) temperatures of Moyo district is higher and is of modified equatorial type of climate.

Methods

Research design

The study was conducted during the *T. indica* fruiting season, from December to March. The *T. indica* sampling sites were chosen from over 300 km apart and took into account differences in AEZs. Each selected AEZ was stratified into two major land use types: crop fields (on-farms) and wild lands. The crop fields (on-farm) were current farmlands for agricultural crops while the wild have not been cultivated for five years or more prior to the study. Four sub-counties (sample sites) were randomly selected in a district, making a total of twelve study sites and covering about 5 km^2. In each sampling site, a total of five *T. indica* trees were selected per land use type based on ease of access, good health indicated by absence of obvious signs of pests, diseases and fire, and presence of visibly good mature pods. The sample trees were located at least 200 meters apart, since trees close to each other may have the same defects such as pests and diseases, fire and hailstorm effects as described by Okello et al.[14,15]

Sample collection methods

Ripe fruit samples were collected from top, middle and bottom third of the tree canopy from the cardinal directions of N-S-W-E using climbing ladders. Ripe pods characteristically have scurfy brown, woody, fragile shells with brown pulp that breaks once when squeezed. Eight pods were collected from each canopy level and a total of 24 fruits were collected from each tree. Four hundred and eighty fruits were harvested from 20 trees per land use type, giving 960 fruits per zone (district) and 2,880 pods from the two land types in the three AEZs. Fruits collected from each tree were pooled, kept in white polythene bags and labelled according to tree number and canopy level, examples T_1C_1, T_1C_2 (representing tree number and canopy level) and taken to Makerere University's College of Agricultural and Environmental Sciences laboratory for analyses.

Samples preparation for laboratory analyses

At the laboratory, the fruits were washed with distilled water and allowed to dry directly on sunshine for about two hours and manually depulped because they were indehiscent. Samples were pooled into land use types for each AEZ. Decomposed and damaged pulp and seeds were removed and discarded. The depulped seeds and pulp were separately sun dried for six hours per day for three days to lower the moisture content and later dried in an oven at 40°C for one day to 8% moisture content. The samples were then separately grounded in an electric grinding machine (Brooks Crompton, 2000 series - UK) to 60-mesh size. The powdered samples were stored in zip lock plastic containers at room temperature for analyses of proximate composition variables.

Proximate assays

All proximate composition analyses were performed in triplicate and the average reading were determined. Moisture content was determined by weighing between 2-4 g of each sample using KEREN model electric weighing scale (EW-N/EG-N series with LCD display) to 99% accuracy and determined according to procedures in AOAC.[21] Total ash, crude oil, crude fibre contents, crude oil were extracted using the soxhlet methods while crude protein were determined using Kjeldhal method according to standard procedures in AOAC.[21] Total carbohydrate was determined as 100 - (∑% of moisture content, total ash, crude protein, crude oil, crude fibre) according to Adepoju and Oyediran[22] and Das et al.[23]

Statistical data analysis

All determination of proximate composition as reported in our study were carried out in triplicate and mean value was calculated. The univariate analysis of variance (ANOVA) in general linear model (GLM) were carried out in IBM SPSS Statistics for windows version 23.0 to determine the differences in proximate composition variables among AEZs and land use types. Treatment means were separated using the least significant difference (LSD) in Post Hoc Tests. The principal component analyses (PCA) was used to interpret the proximate composition variables' relationships among the AEZs and land use types. Significance was set at the probability level of 5%.

Results

Proximate composition of *T. indica* pulp samples

There were significant differences (P<0.05) between AEZs in moisture content and total carbohydrates, but not total ash, crude protein, crude fibre and crude oil (Table 1). Pulp moisture content and total carbohydrates were higher in the Lake Victoria Crescent AEZ while total carbohydrates were higher in West Nile AEZ than in other AEZs. There were no observed significant variation between land use types and proximate composition variables (Table 1). The interactions between AEZs and land use types were significant for total ash, crude protein and crude fibre (Table 1).

Proximate composition of *T. indica* seeds' samples

There were significant differences (P<0.05) between AEZs in moisture content, total ash, crude oil, total carbohydrates but not crude protein and crude fibre (Table 2). Seed moisture content and crude oil were higher in the Lake Victoria Crescent AEZ while total carbohydrates and total ash were higher in West Nile and Eastern AEZs respectively (Table 2). Only total ash contents varied significantly between the land use types as shown in Table 2. The interactions between AEZs and land use types were significant for moisture content and total ash contents.

Table 1 Proximate composition of *T. indica* pulp in the agro-ecological zones of Uganda

	Studied three agro-ecological zones			Two land use types		Agro-ecological zones and land use type interactions						P Value	SE Value
Proximate factor	**West Nile AEZ**	**Lake Vict. Cresc. AEZ**	**Eastern AEZ**	**Wild land use**	**On-farm land use**	**LVC* wild**	**LVC* on-farm**	**Eastern *wild**	**Eastern* on-farm**	**WN* Wild**	**WN* on-farm**	**AEZ* land**	**AEZ* land**
Moisture content	27.40±0.65ᵃ	31.60±0.65ᵇ	27.80±0.80ᵃ	28.70±0.57ᵃ	29.20±0.50ᵃ	31.10	32.10	27.50	28.00	27.50	27.40	0.441	0.401
Total ash	04.60±0.05ᵃ	04.70±0.15ᵃ	05.00±0.45ᵃ	04.60±0.51ᵃ	05.00±0.44ᵃ	04.40	05.00	04.30	05.70	05.00	04.20	0.017	0.267
Crude protein	15.70±0.81ᵃ	16.10±0.57ᵃ	15.70±0.38ᵃ	15.90±0.65ᵃ	15.70±0.32ᵃ	15.70	16.50	16.50	14.80	15.50	15.90	0.008	0.280
Crude fibre	07.10±0.57ᵃ	08.40±0.50ᵃ	07.60±0.62ᵃ	07.40±0.32ᵃ	08.00±0.60ᵃ	09.30	07.60	06.80	08.40	06.80	08.40	0.048	0.602
Crude oil	00.28±0.02ᵃ	00.27±0.01ᵃ	00.29±0.01ᵃ	00.30±0.02ᵃ	00.26±0.02ᵃ	00.30	00.24	00.30	00.28	00.30	00.26	0.952	0.060
Carbo hydrates	56.20±0.80ᵃ	50.20±0.90ᵇ	55.10±1.54ᵃ	54.20±0.96ᵃ	53.40±1.40ᵃ	50.10	50.20	56.20	53.90	56.40	56.00	0.521	1.039

±, standard deviation; *, interactions between land use and agro-ecological zone with variables; same superscript letter within row shows no significant difference

Table 2 Proximate composition of *T. indica* seeds in the agro-ecological zones of Uganda

	Studied three agro-ecological zones			Two land use types		Agro-ecological zones and land use types interactions						P Value	SE Value
Proximate factor	**West Nile AEZ**	**Lake Vict. Cresc. AEZ**	**Eastern AEZ**	**Wild land use**	**On-farm land use**	**LVC* wild**	**LVC* on-farm**	**Eastern *wild**	**Eastern *on-farm**	**WN* wild**	**WN* on-farm**	**AEZ* land**	**AEZ* land**
Moisture cont.	09.00 ± 0.51^a	13.90 ± 0.51^b	13.20 ± 0.25^b	12.40 ± 0.60^a	11.60 ± 0.40^a	15.70	12.10	12.70	13.50	08.90	09.20	0.001	0.335
Total ash	02.30 ± 0.07^a	02.20 ± 0.24^b	02.40 ± 0.08^a	02.20 ± 0.11^a	02.30 ± 0.09^b	02.10	02.30	02.30	02.50	02.40	02.20	0.007	0.038
Crude protein	04.50 ± 0.05^a	04.90 ± 0.08^a	04.30 ± 0.05^a	04.80 ± 0.10^a	04.30 ± 0.09^a	04.80	04.90	04.90	03.80	04.70	04.30	0.154	0.299
Crude fibre	09.00 ± 0.13^a	08.60 ± 0.08^a	08.00 ± 0.60^a	08.70 ± 0.32^a	08.40 ± 0.14^a	09.10	08.10	07.20	08.90	09.90	08.10	0.109	0.748
Crude oil	02.98 ± 0.05^a	02.98 ± 0.15^a	02.64 ± 0.10^b	02.83 ± 0.09^a	02.91 ± 0.10^a	02.98	02.99	02.70	02.59	02.81	03.15	0.129	0.097
Carbo hydrates	61.00 ± 0.75^a	56.20 ± 0.96^b	58.00 ± 0.95^b	57.90 ± 0.57^a	59.00 ± 0.76^a	54.50	58.00	58.60	57.60	60.50	61.50	0.424	1.177

±, standard deviation; *, interactions between land use and agro-ecological zone with variables; same superscript letter within row shows no significant difference

Proximate composition variables' relationships of *T. indica*

Generally, there were no observed relationships among pulp and seeds proximate composition variables between the AEZs and land use types. Additionally, there were observed strong correlations among all proximate composition variables with exception of pulp crude oil, which has a weak correlation. The proximate variables clustered together and relatively far from the origin are all correlated. Seed moisture content is closer to the pulp moisture content and pulp crude fibres than to any of the proximate variables, indicating a higher correlation between moisture contents and crude fibres, which is also evident in the data in Figure 2. The angle between seed moisture content, the origin and crude protein contents is less than 90 degrees, which indicates that there is a degree of positive correlation between them. Total ash contents have negative correlations with all the proximate variables other than seed moisture content and pulp crude fibre and this can be discerned from Figure 2 by noticing that the angle formed with the origin is greater than 90 degrees. By considering only Figure 2, it is assume that the strongest negative correlation is between total ash contents and crude protein contents seed crude oil and seed crude fibre. However, Figure 2 is only charting 2 dimensions (First and Second Components) but the data has 12 dimensions (variables) and thus the figure may get some of the fine details wrong as it can only show the main patterns.

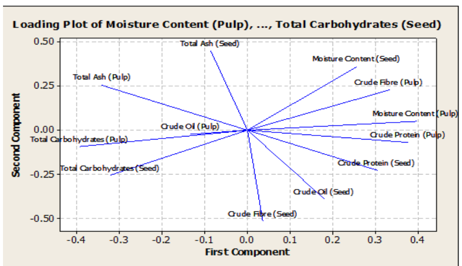

Figure 2 Principal Component Analysis of *T. indica* Pulp and Seed Proximate Variables' Relationships.

Discussion

Moisture contents

Generally, the pulp samples had high on-dry basis moisture content (27.40-31.60%) than seed samples (9.00-13.90%). The moisture content of conventionally dried fruits are about 15% while fresh fruit is typically between 75 and 95% water, a fact that helps to explain the refreshing character of the food. Foods rich in moisture are easily susceptible to the microbial attack. Moisture content is among the most vital and mostly used measurement in the food processing, preservation, storage, legal and labelling, economic, microbial stability and food quality. Inappropriate moisture amounts is very damaging to the useful life of food, much effort is put into reducing the water content of dry foods in order to prolong their shelf lives. It affects the physical and chemical contents of food which relates to its freshness and stability for storage thus determines the shelf life of food material. Moisture of food is considered as a good source of water and 20% of total water consumption is necessary to come from food.[24] Chiteva & Kituyi[25] and El-Siddig et al.[13] documented values which are within the range of our study but lower values were documented by Ballal Taha SA & Sulieman AME[26,27] while[28] recorded higher values from the same species.

Most fruits have very high water content (80-95%) at harvest and the rate of water loss from fruits is affected by the shape and structure of the produce, the plant factors as well as the environmental conditions such as temperature and relative humidity.[29] The observed moisture contents variations are probably due to the differences in eco-factors and climatic factors that differ with AEZs which agrees with Okello et al.[14,15] However, the low moisture content in the study's *T. indica* seeds are probably due to the nature of sample (dry), double protective nature of both the pod and seed coat (testa) to prevent excessive moisture loss, which corroborates with.[30] While the differences in the shape and structure of *T. indica* fruits and seeds could have also greatly contributed to the observed differences. This corroborates with a report by Akajiaku et al.[31] who documented that *T. indica* are bean like irregular curved pods and seeds are irregular shaped, flattened or rhomboid and very hard and shiny. Storage conditions, duration before analysis, variation in processing methods, harvest and postharvest handlings, probably contributed to the observed differences and agrees with other studies.[14,15]

The fruit species show different behaviour depending on moisture and dry matter.[32] Water-rich fruits and vegetables provide human natural sugars, amino acids, mineral calories and vitamin requirements. The highest and lowest average moisture contents were recorded in Lake Victoria Crescent and West Nile AEZs respectively, probably due to the photosynthesis and transpiration processes in these zones. This agrees with Bebija & Yamin[33] who reported the decreasing rate of photosynthetic and transpiration process during winter had effects on the observed moisture contents of *Bambusa tulda*. The low moisture content of observed in this study shows that the products can be stored for long, suggesting that the pods have higher shelf life than some common plant species hence long storage will not results into immediate decay due to microorganism attacks. Stored foods are commonly used as famine and staple foods for the rural farmers in Uganda, which also helps in improving household nutrition, poverty alleviation and income generation,[14,15] and are also used as planting materials. The products are therefore recommended for processing, preserving and storage if it is not immediately consumed to alleviate famine. Because the samples' moisture contents are low, they can help obese people to manage their weight while the low moisture guarantees a good keeping period.

Total ash contents

The total ash content of 2.20-2.40% and 4.60-5.00% dry matter of seeds and pulp respectively are higher in pulp than seeds samples. The total ash represents the total mineral content in foods. Total ash content is generally taken to be a measure of the mineral content of the original food.[9] The ash content in foods help determine the amount and type of minerals in food. And because certain foods are high in particular minerals, total ash content becomes important.[10,27] In food, total ash contributes the residue remaining after all the moisture has been removed and organic material (fat, protein, carbohydrates, vitamins, organic acid and others) have been incinerated at a temperature of about 500°C. The total ash content of the samples in our study was close to the results earlier reported for the same species[10,13,25-27,31] but higher than those reported by Krithika and Radhai.[28] However, our study findings disagree with Yusuf et al.[11] who reported lower results in *T. indica* pulp than in seeds, indicating the pulp contain relatively large amount of some other mineral elements than the seeds.

The total ash content of most fresh foods rarely is greater than 5%.[11] The high ash contents present high concentrations of minerals that catalyse metabolic processes and improve growth and development. Lower total ash content values in seeds are desirable because of its effect on biomass energy value; the higher the total ash content the lower the energy value.[34] The *T. indica* total ash content values, especially the pulp are within most conventional fresh food values. The values documented in this study may be attributed to the differences in ecofactors, climatic factors and plant species in the different AEZs, which agrees with Zaragozá[32] and Okello et al.[14,15] Pulp samples, Eastern AEZ and on-farm land use type have more total ash contents in our study.

Crude proteins

Crude protein levels of 15.70-16.10% (pulp) and 4.30-4.90% (seeds) respectively, is about 4 times higher in the pulp than the seed samples. Unlike animal foods that contain all of the essential amino acids and are called complete proteins, plant foods do not have complete proteins and are incomplete protein. Complete proteins are obtained by eating combinations of plant foods. About 20% of the human body is made up of protein. Protein plays a number of functions in the human body-building material for skin, bones, muscles and other tissues in the body. It is a regulator of fluid balance and acid-base balance; major component of enzymes, antibodies and hormones; act as transporters in the body, and used for energy. Crude protein values in this study exceed values documented in other studies[22–25] but lower than values reported by Yusuf et al.[11] and disagree with De Caluwé et al.[35] who reported the *T. indica* seeds are good sources of protein than pulp. According to Pamela,[36] proteins from plant sources have lower quality but their combination with many other sources of protein such as animal protein result in adequate nutritional value. However, the plant foods providing more than 12% of its caloric value from protein is a good protein source.[37]

The differences in crude protein values are probably associated with differences in environmental conditions across the AEZs and land use types which corroborates with a study by Okolosi et al.[34] And climatic factors may also have caused the differences in different AEZs. Our study showed that the pulp samples which are rich sources of crude protein can encourage their use in human diets and might be helpful for protein energy malnutrition compared to seed samples which are low source of protein. Since the *T. indica* protein can supplement plant protein sources (beans and peas) widely consumed in many rural homes, encouraging consumption of pulp and seeds among the rural communities in the study areas and beyond can lead to the provision of good protein supplement in human and animal diets. The consumption of *T. indica* are linked with many health benefits such as lower body weight, lower cholesterol and lower blood pressure levels, lower risk of stroke, cancer and death from heart disease. Pulp samples, Lake Victoria Crescent AEZ and wild land use type had higher crude protein values, indicating they are good sources of crude protein to the population. This also probably explains why little attention is paid to the use of seeds as protein source in Uganda.

Crude fibre

The crude fibre values obtained for *T. indica* pulp and seeds were 7.10-8.40% and 8.00-9.00% dry matter of pulp and seeds respectively. Fibre is an important part of diet and the consumption of dietary fibre is important for optimal health.[38] Crude fibre is made up largely of cellulose together with a little lignin which is indigestible in human.[9] Although crude fibre enhances digestibility, its presence in high level can cause serious health problems. Foods with high fibre content are considered good for diabetic patients and also reduce blood cholesterol, obesity and diabetes.[39] The values of crude fibre in our study are lower than values documented by Abdel et al.[27] but higher than values recorded by other authors[11,31] while[26] recorded values which are within the study values. The study findings also agree with De Caluwé et al.[35] who reported in their study that the *T. indica* seeds are good sources of fibres than pulp.

The variation in crude fibre values of *T. indica* could have been influenced by the climatic factors and eco factors. This corroborates with Akajiaku et al.,[31] who documented in their study that climatic and environmental factors are responsible for the observed differences in crude fibres. Seed samples and Lake Victoria Crescent AEZ had higher values indicating good source of crude fibre. Crude fibre values documented are below the recommended dietary allowance in children (19-25%) and lactating mothers (29%) as documented by Ishida et al.[40] Thus *T. indica* products studied are not good sources of crude fibre. However the low level of crude fibre is considered appropriate, because it aids absorption of glucose and fat. Fruits that contain low fibre levels are included in weaning diets. Both samples (pulp and seeds), all AEZs and land use types have similar crude fibre values indicating its importance n the selected AEZs.

Crude oil

The crude oil values documented for *T. indica* pulp and seed contents were 0.27-0.29% and 2.64-2.98% respectively. The crude oil contents in seed samples were higher (more than 10times) than that of pulp. Lipids are necessary because they provide maximum energy and facilitate intestinal absorption and transportation of fat-soluble Vitamins (A, D, E, K) and carotenoids.[32] Fats are most typically associated with the waxy cuticle surface of the fruit skin. Fats, proteins and carbohydrates in dried foods are present in larger amounts per unit weight than in their fresh foods and the nutrient value of most rehydrated foods is comparable to that of fresh items. Lipid content of foods varies widely but quantisation is important because of regulatory requirements, functional properties and nutritive value.[8] Fat in food is considered as a main source of energy, essential fatty acids and vitamins.[37] Lipid provides very good sources of energy and aids in transport of fat soluble vitamins, insulates and protects internal tissues and contributes to important cell processes.[36] The crude oil contents of *T. indica* samples in the present study were lower than oil contents reported by other authors[11,13,26-28,31] in the same species but higher than oil contents documented elsewhere.[25]

Our study documented similar values of crude oil contents in all the AEZs and land use types. It thus disagrees with Maranz and Weisman[41] who documented high elevations and cool temperatures are associated with the high levels of oil. The effects of temperature, rainfall, altitude and land use types probably had very little effects on the samples' oil contents. The variation in crude oil content of *T. indica* fruit (pulp and seeds) across the different AEZs of Uganda is simply a response to climatic, ecological conditions and cultivar type. This agrees with findings that found crude lipid content of *V. paradoxa* to vary across agro-ecologies in the Guinea savanna of Nigeria.[34] Thus both pulp and seed samples when compared to conventional plants, vegetable, fruits see[34,42,43] are poor sources of oil that makes the staple foods with them good for obese people. Due to its low oil contents, Uganda's *T. indica* does not qualify as supplement to some conventional and locally available oil seeds (examples, ground nuts, soybeans and sunflower) and can be recommended in weight-reducing diets.

Total carbohydrates

The pulp and seed total carbohydrates values ranged from 50.20-56.20% and 56.20-61.00% respectively. Typically, fruits are high in carbohydrates, although a large range (2-40%) is possible. Carbohydrates are important in foods as a major source of energy, to impart crucial textural properties, and as dietary fibre which influences physiological processes.[44] Carbohydrates are all about energy and are found in foods like fruits, vegetables, breads, pasta and dairy products. Fruit carbohydrates could supplement scarce cereal, their deficiency causes depletion of body tissue. Moisture contents accounts for 9.0-31.6% on dry weight basis of *T. indica* carbohydrate in this study and it is a dominant factor in determining the proximate of *T. indica* food products. Carbohydrate levels are within the range reported earlier see[11,13,25,26,28,31] but higher than values documented by Abdel et al.[27] However, Alessandra et al.[45] reported the wide range total carbohydrate levels for various native Amazonian fruits (11.09-50.13%) while Charrondiere et al.[46] reported both available and unavailable carbohydrates, the latter are considered as dietary fibre.

Total carbohydrates in fruits depend on the type of fruit and its maturity. A large portion of the carbohydrates present in fruits is fibre, free sugars (fructose, glucose, sucrose and other sugars) and starches which are typically converted to sugars during the ripening process. Fruit energy value is inversely proportional to moisture content.[32] The amount of carbohydrate in the diet - high or low is less important than the type of carbohydrates. Samples with low carbohydrate content are ideal for diabetic and hypertensive patients requiring low-sugar diets.[32] The present investigation shows that *T. indica* are fairly good source of carbohydrates compared to other food sources.[11,45] Total carbohydrates values were probably influenced by moisture content leading to diversity among the samples across the AEZs. Throughout the world, different sets of energy conversion factors are used as well as different nutrient definitions are always used.[46] These can both have impacts on the energy values of foods and energy intake calculations. The consumption of *T. indica* pulp and seeds provide an immediate source of energy. The *T. indica* is a moderate carbohydrate source when compared with common legumes, can contribute to the body's caloric requirements, recommended as a supplement for human and animal intake.

Conclusion

There were significant differences ($P<0.05$) between agro-ecological zones and proximate composition variables. No observed relationships among all proximate composition variables between the AEZs and land use types. The Lake Victoria Crescent AEZ had higher values of proximate composition variables than other AEZs. Proximate composition values (moisture contents, total ash and crude protein) were superior in pulp while seeds were rich in crude fibres, crude oil and total carbohydrates. Both pulp and seeds showed good proximate contents, but the traditionally inedible seeds (thrown away after depulping) have more prospects and are recommended for consumption due to the high crude fibre, crude oil and total carbohydrates contents than pulp, but first need to be processed before incorporation into human and animal diets. The study is expected to contribute to the enrichment and composing the food proximate composition database for Uganda which is essential for the rural households' food security and nutrition, human health, research and policy programme planning.

Conflicts of interest

No conflicts of interests was declared.

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