MORPHOLOGICAL AND NUTRITIONAL CHARACTERISTICS OF *TAMARINDUS INDICA* (LINN) FRUITS IN UGANDA

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DECLARATION

I, Jaspher Okello, hereby declare that the information presented in this dissertation is my original work and has never been submitted for an award in any university or institution of higher learning. The work presented here is my own. Where information is obtained from other works, the sources are acknowledged. All photographs were taken by Jaspher Okello.

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This dissertation has been submitted for examination with the approval of the following University Supervisors:

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Associate Professor Gerald Eilu Date

DEDICATION

This work is dedicated to my daughter Hope Edinah, wife Dorcus and brother Denis Hamson Obua.

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ABBREVIATIONS, ACRONYMS AND CHEMICAL SYMBOLS

µg	=	Microgram
BoP	=	Breadth of pod
bp	=	Boiling point
Ca	=	Calcium
Cu	=	Copper
DNA	=	Deoxyribonucleic acid
Fe	=	Iron
K	=	Potassium
kg	=	Kilogram
LoP	=	Length of pod
m	=	Meters
masl	=	Meters above sea level
MC	=	Moisture content
Mg	=	Magnesium
mg	=	Milligram
Na	=	Sodium
NFE	=	Nitrogen Free Extractives
NORAD	=	Norwegian Agency for Development Cooperation
NRC	=	National Research Council
P	=	Phosphorus
PE	=	Petroleum Ethers
RDA	=	Recommended Dietary Allowance
T1C1,	=	Tree number 1 and canopy number 1
T1C2	=	Tree number 2 and canopy number 2
T1C3	=	Tree number 3 and canopy number 3
S	=	Seconds
Zn	=	Zinc

ABSTRACT

An evaluation of morphological and nutritional characteristics of *Tamarindus indica* L. (Fabaceae) pod pulp and seeds was carried out on samples from three agro-ecological zones (West Nile, Eastern and Lake Victoria Crescent) in Uganda. A total of 2,880 sample pods (24 pods/tree) was collected and analysed. The morphological characteristics of pods (length, breadth, mass, seed number and mass) as well as pulp were analysed. The mean values of *T. indica* morphological characteristics were higher in the Lake Victoria Crescent zone samples and fallow land use types than other zones' samples. The samples from West Nile zone had the highest maximum pod length values, mean and standard deviations than other agro-ecological zones. The mineral elements in the samples decreased in the order: Mg > Ca > Na > Fe > K > P > Zn. The samples from the Lake Victoria Crescent zone (fallow land use type) had higher mineral levels than the other zones and land use types. In terms of proximate and physico-chemical content, relatively higher values were recorded for moisture, ash, protein, fibre, oil, carbohydrates, vitamin C and beta carotene compared to studies documented elsewhere. The differences in the morphological characteristics between agro-ecological zones and land use types calls for the recommendation of both pulp and seeds for consumption, domestication, commercialisation and species improvement. *Tamarindus indica* growing in the fallow land use type is recommended for retention on farm, future research development, promotion for consumption and commercialisation. The high level of ash in *T. indica* shows that it can not only be used as the sole source of ash for human and animal consumption, but can also be incorporated in the diet.

Key words: morphology, nutritional value, mineral content.

STRUCTURE OF DISSERTATION

This dissertation is structured into seven chapters. Chapter One covers the general background to the study, statement of the problem, objectives, hypothesis and justification. Chapter Two presents a review of the state of the knowledge on *Tamarindus indica* pod pulp and seeds. Chapter Three describes the study area and methods. The results are presented in those separate chapters. Chapter Four covers the morphological characteristics; Chapter Five presents mineral composition, while Chapter Six presents the proximate composition and physico-chemical parameters of *T. indica* seeds. Chapter Seven contains the general conclusions and recommendations.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Wild food plants are used in the diet of rural people worldwide (Murray *et al.*, 2001). Fruits from indigenous trees such as baobab and *Tamarindus indica*, for instance are important for ensuring food security in rural areas. According to Sitske *et al*. (2007), the contribution of wild food plants to combating deficiencies in vitamins and micronutrients is essential in the agriculturally marginal areas. Wild food plants are particularly most important during periods of food scarcity (Aline *et al*., 2008).

A report by NRC (2008) indicates that wild fruits are useful for adding culinary variety, flavour, nutrients, and energy to diets. The pulp of *T. indica* pod is, for example, eaten fresh or as an ingredient in fruit drinks, jams, chewing gums and other products. In Uganda, the *T. indica* pulp is mixed into the local millet porridge or bread and eaten as a delicacy (Katende *et al*., 1999). It is also used for making local juice, eaten as snack and common in the rural population diet.

There are various examples to show the importance of wild food plants. In Swaziland, for example, people eat products from over 220 species of wild plants, about half of them fruits (Antonsson-Ogle, 1990). In Cameroon, there are over 300 trees (including 200 forest species) whose fruits or seeds are eaten (NRC, 2008). In Uganda, over 105 wild fruits trees, including *T. indica* are eaten as food (Goode, 1989).

According to Schabel (2004), *Tamarindus indica* is genetically diverse, as reflected primarily in the variability of its fruits in terms of size and taste (sweet or acidic pulp).

Apart from having differences among fruit types in the different continents, a subspecies with red fruit (*T. indica* spp *rhodocarpa*) occurs in India (Parrotta, 1990). According to NRC (2008), the adaptability of *T. indica* to various climatic zones and environmental conditions is the key factor contributing to its importance in the tropics. No studies however, evaluated the relationship between the characteristics of *T. indica* pods and seeds from different agro-ecological zones in Uganda.

Whereas *T. indica* occurs in different agro-ecological zones of Uganda, it is not clear whether the populations have phenotypic, genotypic or nutritional differences. Because of this, the present study investigated the morphological and nutritional characteristics of *T. indica* pods from the different agro-ecological zones in Uganda.

1.2 Statement of the Problem

The importance of many wild-fruits is unknown (NRC, 2008). Although wild fruits provide many benefits, factors influencing their distribution are not well known (NRC, 2008). Even when variability in *T. indica* is manifested, for example, in different fruit sizes and nutritional characteristics, it is not clear whether the differences relate to the environmental factors within Uganda. Characterisation of morphological traits of *T. indica* from the different zones was needed to provide information for propagation, on-farm growing, as well as off-farm management and conservation of *T. indica* in Uganda and also investigate nutritional differences.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this study was to determine the morphological and nutritional characteristics of *T. indica* pods from the different agro-ecological zones in Uganda.

1.3.2 Objectives

The objectives were:

(i) To examine the variation in morphological characteristics of *T. indica* pods in the different agro-ecological zones in Uganda.

(ii) To determine variations in the nutrient composition of *T. indica* pods from the different agro-ecological zones in Uganda.

1.4 Hypotheses

(i) Ho: There is no significant difference in the morphological characteristics of *T. indica* pods from the different agro-ecological zones in Uganda

(ii) Ho. There is no difference in nutrient composition of *T. indica* pods from the different agro-ecological zones in Uganda.

1.5 Justification

Determination of morphological and nutritional characteristics of *T. indica* pods is aimed at promoting its conservation. Information generated from this study can be used to guide selection of *T. indica* trees for domestication and utilisation. Information on nutritional composition can be used to promote the use of *T. indica* pulp and seeds for animals and humans food locally and as a commercial product locally and internationally.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Indigenous Wild Fruit Trees

Indigenous fruits contribute on average 42% of the natural food basket of rural households in southern Africa (Campbell *et al*., 1997). They are used to generate income through the sale of fruits and fruit products, medicine, gums and resins (Maghembe and Seyani, 1992). The fruits are also used to compliment or supplement diets because they contain vital nutrients and essential vitamins (Maghembe *et al*., 1998). For example, *T. indica* fruits are rich in protein, carbohydrates, fibres, vitamin C and other minerals (Pugalenthi *et al*., 2004; Parvez *et al*., 2003).

2.2 *Tamarindus indica*

Tamarindus indica (syn. *T. occidentalis* Gaertn.; *T. officinalis* Hook.) belongs to the family Fabaceae, sub-family Caesalpiniaceae (Lewis *et al*., 2005). It belongs to a monotypic genus, containing one species, *T. indica* (El-Siddig *et al*., 2006). According to ICUC (1999), the genetic diversity of *T. indica* in Asia and Africa varies with fruit, flower colour and sugar ratio in the fruits. The variations in size, shape, flavour and colour of *T. indica* fruits and seeds are reported in many studies representing various uses in these areas.

In the different regions of Sudan, fruits from eastern part of the country are reported to be longer than fruits from central Sudan. In addition, the fruits from central region have been reported to be sweeter than those from eastern Sudan (Gebauer *et al*., 2002), showing the influence of agro-ecological zones on the taste. Although the agro-ecological zones of Uganda are known (GoU, 2004), valuable tree species such as *T. indica* from these zones have not been characterised in terms of morphologically and nutritional values.

2.3 Morphology of *T. indica* Pulp and Seeds

According to Nagarajan *et al*. (1998), *T. indica* has extensive variations in characteristics such as fruit size. The pods have been noted to vary in size and shape (Haynes *et al.*, 2006), some of them straight to curved, scaly, with a grey to rusty brown outer epicarp, and oval in cross section (Schabel, 2004). The pod has the firm soft pulp which is thick and blackish brown (El-Siddig *et al.*, 2006). They are indehiscent and brittle (Joker, 2000), containing 55% edible pulp (Krithika and Radhai, 2007). In Africa, there are generally few studies of morphological characteristics of *T. indica* (Yusuf *et al.*, 2007); creating a knowledge gap that ought to be filled.

2.4 Uses of *T. indica*

T. indica pulp is valued and widely used in food, beverages and medicine. It has therapeutic uses for constipation, abdominal pains, bowel obstruction, pregnancy vomiting and intestinal disorders among others (Nacoulma, 1999). While in India where many studies have been carried on *T. indica*, seeds are used as cattle feed because of the high protein content, (Krithika and Radhai, 2007).

In Uganda, *T. indica* tree has many uses, making it multipurpose (Kakuru *et al.*, 2004). The fruits, leaves, bark and roots of *T. indica* have various uses such as firewood, charcoal, poles and timber. Other uses include source of food (pulp for fruit drink, porridge and spicing sweet potato and cassava bread), fodder (leaves, fruit) and fruits, leaves and root for herbal medicine (Katende *et al*, 1999). In addition, many communities in Uganda have traditional beliefs attached to the tree e.g. in West Nile, the communities of Pakele and Bileaffe in Adjumani and Arua districts consume *T. indica* pulp as a preventive measure during epidemic diseases' outbreak.

2.5 Composition of *T. indica* Pulp and Seeds

Variations in the chemical composition of *T. indica* pulp from different regions have been reported (Chiteva and Kituyi, 2006). It contains amounts of Zn, Ca and Fe required for consumption (Glew *et al*., 2005). The seeds are also potential commercial sources of major mineral elements (NRC, 2008; Yusuf *et al.*, 2007; Ibironke *et al*., 2006).

A report by Yusuf *et al.* (2007) indicates that *T. indica* seeds and pods have generally high organic matter contents. The seeds have also been reported to contain high contents of carbohydrates, protein, and fat, as well as small amounts of vitamins and carotene (Krithika and Radhai, 2007). Although *T. indica* pulp is poor in protein and fat, the seed is a good source of both protein and fat. In Kenya, Chiteva and Kituyi (2006) reported generally low protein levels in various samples of *T. indica* pulp from different divisions in the country (Table 2.1).

Table 2.1 Proximate Composition of *T. indica* Fruit Pulp from Kenya

District & Division	MC (%)	Crude fibre (%)	Sulphated ash (%)	Crude fat (%)	Vit. C	Protein (%)	CHO (mg100/g)	Calorific V (kcal)
Kitui Kavisuni	18.35	5.30	4.53	0.17	8	0.01	71.8	2.85
Kitui Mbitini	26.10	5.23	5.41	0.11	8	-	63.2	2.94
Mwingi Katse	18.30	6.75	5.15	0.44	8	0.02	69.3	2.90
Mwingi Kyandundu	28.30	3.30	4.59	0.42	8	0.02	63.4	2.86
Makueni TARDA	24.00	5.06	7.91	0.04	8	0.02	63.0	2.82
Makueni Makindu	32.60	5.50	6.31	0.04	8	0.01	55.5	2.85

Source: Chiteva and Kituyi (2006). Where; MC = moisture content; Vit. C = vitamin C; CHO = carbohydrates; Calorific V = calorific value (kcal)

A study conducted by El-Siddig *et al.* (2006) found that *T. indica* in Sudan had low water content but high protein, carbohydrate and mineral levels. They thus, concluded that this composition relates to locality. The saponification value of the oil of *T. indica* has also been reported by Ishola *et al.* (1990) to be higher than iodine value, Table 2.2.

Table 2.2 Physico-chemical Properties of *T. indica* Pulp and Seeds' Lipid

Constituents	**Pulp**	**Seeds**
Saponification value (mgKOH/g)	301.3	266.6
Iodine Value	120.6	78.1
Unsafonified matter (g/kg)	139.0	31.3
Acid value (g/kg)	896.0	292.6
Free fatty acid (g/kg)	448.0	46.3
Peroxide value (m Eq/kg)	123.3	98.9

Source: Ishola *et al.* (1990)

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CHAPTER THREE

THE STUDY AREA

3.1 Location and Description of Study Sites

The study covered three districts of Uganda (Soroti, Moyo and Nakasongola) within the agro-ecological zones of eastern, Lake Victoria Crescent and West Nile respectively (Figure 3.1).

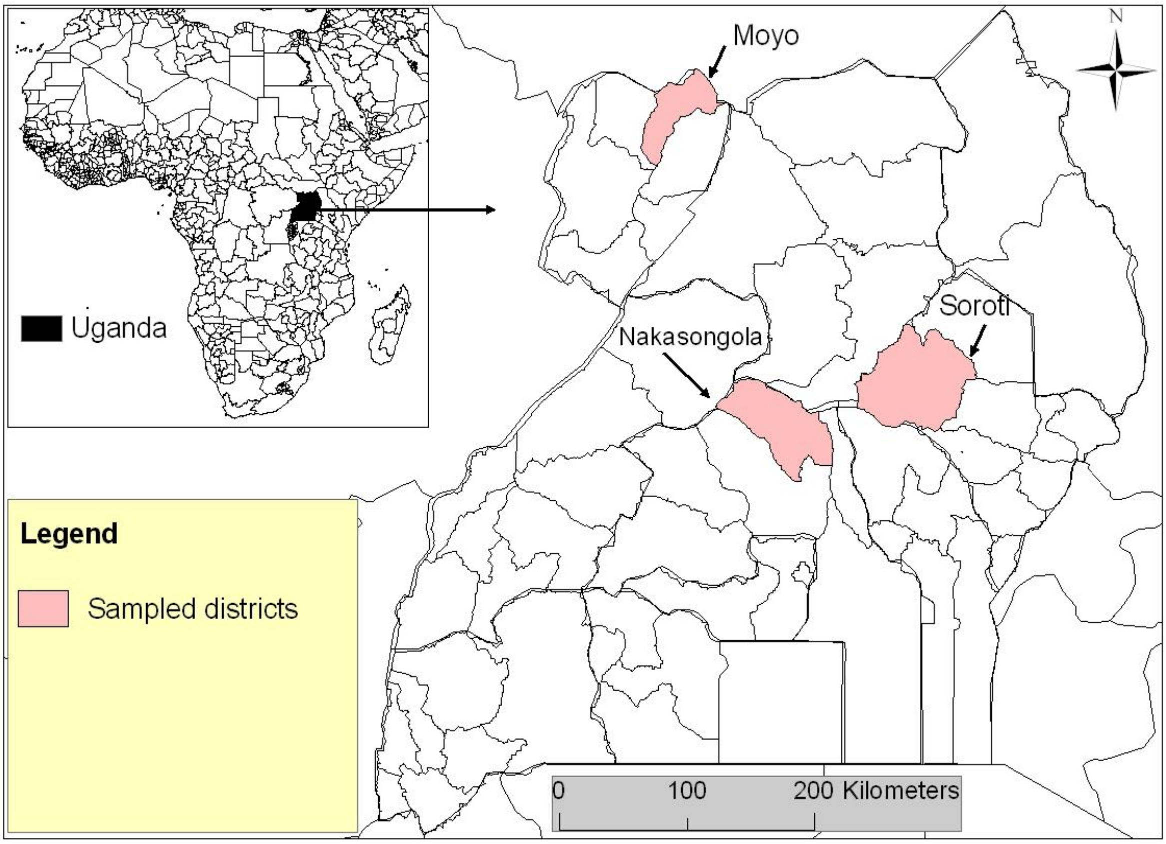

Figure 3.1. Map of Uganda showing the study sites in the three agro-ecological zones

Each district is representative of the agro-ecological zone and has populations of *T. indica*. The characteristics of the study sites are summarised in Table 3.1.

Table 3.1 Summary of Key Characteristics of the Districts from which *T. indica* Fruits were Sampled

Major Feature	**Nakasongola**	**Soroti**	**Moyo**
Region in Uganda	Central	Eastern	Northern
Grid reference: Lat.	1°00'N & 1°40'N	1°20'N & 2°05'N	3 °10'N & 3 °55'N
Long.	32°00'E & 32°45'E	33°08'E & 33°50'E	31°25E & 32°10'E
Agro-ecological zone	Lake Victoria Crescent	Eastern	West Nile
Area (km^2)	3,510	3,374	1,891
Altitude (masl)	1,000 – 1,400	1,036 - 1,127	600 (Nimule) - 1,586
Vegetation type	Open deciduous savannah woodland	Wooded savanna, grassland savanna, forests, riparian	wooded savanna
Major geological formation	Bululi and Lwampanga	Granites, mignalites, gneiss, schists and quartzites	Gneiss, alluvial deposits, schist, quartzite, marble
Major soil types	Basement complex formations of the pre-Cambrian age	Serere and Amuria catena, Metu complex, Usuk series	Vertisols, leptosols, alluvial deposits, ferrasols
Agricultural productivity	Most areas of are very productive	Moderate productivity	Fair to moderate productivity
Rainfall (mm pa)	875 - 1,000	1,000 - 1,500	1,500 - 1,700
Rainfall pattern	Bimodal	Bimodal	Less pronouncedly bimodal
Rainy seasons	March – July and October -December	March - June and August - November	March - June and August - November
Min - max temperature (°C)	25 – 28	18 31.3	23.7 - 30

Adapted from NEMA (2004a); NEMA (2004b); NEMA (1997)

The districts differ in terms of general climate and soils but are similar in rainfall patterns, rainy seasons and crops grown. The topography of Nakasongola is generally flat, characterized by minimal altitudinal differences with poor drainage in the wide flat valleys and shores of Lake Kyoga. The district is endowed with unique rocky outcrops (isenbergs), (NEMA, 2004a). Soroti district is mainly underlain by rocks of the basement complex precambrian age which include granite, mignalite, gneiss, schists and quartzite (UCC, 2003). The characteristic physical features of Moyo district include low plains as well as rolling hills and valleys that slope towards River Nile at approximately 900 masl. These rise in series of hills and peaks in the northern and north eastern parts of the district (NEMA, 2004b). The main geological formations in Moyo district include gneiss, alluvial deposits, schist, quartzite and marble. The schist, quartzite and marble occur in the mountains. The soils are generally moderately fertile (NEMA, 2004b). Over the past five years, the high average annual temperature of 25.6^{0} C and a low of 23.7^{0}C (UDIH, 2007).

3.2 The Agro-ecological Zones of Uganda

Uganda has been zoned into 10 broad agricultural production, agro-processing and marketing zones (Table 3.2) for the purposes of maximizing agricultural benefits (GoU, 2004).

Table 3.2 Detailed Agro-ecological Zones of Uganda

Sn	Agro-ecological zone	Agro-ecological District
1	Southern Highlands	Kisoro, Kabale, Rukungiri, Kanungu
2	Southern Dry lands	Rakai, Sembabule, Mbarara, Ntungamo
3	Lake Victoria Crescent	Masaka, Mpigi, Luwero, Kampala, Mukono, Kayunga, Wakiso, Kiboga, Nakasongola, Kalangala, Mubende
4	Eastern	Pallisa, Tororo, Kumi, Kaberamaido, Katakwi, Soroti, Mbale, Sironko, Kapchorwa
5	Mid Northern	Lira, Apac, Kitgum, Gulu, Pader
6	Lake Albert Crescent	Masindi, Hoima, Kibale
7	West Nile	Arua, Moyo, Adjumani, Yumbe
8	Western Highlands	Bushenyi, Kasese, Bundibugyo, Kamwenge, Kyenjojo, Kabarole
9	South East	Jinja, Iganga, Bugiri, Busia, Kamuli, Mayuge
10	Karamoja Dry lands	Moroto, Kotodo, Nakapiripiri

Source: GoU (2004)

The zones are also 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 zone but differ between zones. In each zone, the conditions (topography, soil types, rainfall), as well as farming systems and practices are fairly homogeneous (Mwebaze, 2002).

3.3 Distribution of *T. indica in Uganda*

Tamarindus indica has a wide geographical distribution in the subtropics and semi-arid tropics where it is cultivated (El-Siddig *et al*., 2006). It is widely distributed in Africa, Asia and West Indies (Nagarajan *et al*., 1998). It thrives well in semi-arid areas - including alkaline, slightly saline and poor soils. Although considered a dry land species, its occurrences in the Philippines, Indonesia, Singapore, Thailand and Hawaii shows that it has high tolerance for humidity (NRC, 2008). It grows at about 1500 masl, with preference for riparian, well drained sites in woodlands, alluvial flats, scarp slopes, deciduous thickets and around termite mounds (Schabel, 2004).

In India, it is distributed continuously in southern and central regions (which have similar wet and semi-arid climatic characteristics of tropical regions. It also occurs in sparse patches up in Northern India. In Africa, *T. indica* is commonly found in woodlands, and is well adapted to the arid and semi-arid zones (Coronel, 1991). In Uganda, *T. indica* is found in four main agro-ecological zones: West Nile, Lake Victoria Crescent, eastern and mid northern characterised by savana vegetation and dry period with maximum temperatures about $30^{O}C$ (NAADS, 2006; GoU, 2004 and Katende *et al*., 1999).

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CHAPTER FOUR

MORPHOLOGICAL CHARACTERISTICS OF *TAMARINDUS INDICA* PODS AND SEEDS FROM SELECTED AGRO-ECOLOGICAL ZONES IN UGANDA

Abstract

The morphological characteristics of *Tamarindus indica* LINN pods and seeds from three agro-ecological zones in Uganda were investigated between December 2007 and March 2008. The agro-ecological zones of Uganda differ in terms of agro-climatic and soil conditions. The aim was to examine the variation in morphology of *T. indica* pods in different land use types. A total of 2880 pods (24 from each of 20 trees sampled in each land use type) were collected and analysed. The pods were measured for morphological parameters (length, breadth, number of seeds) and pulp mass. Means for each parameter were computed and two-way analysis of variance (ANOVA) was carried out using SPSS to determine if there were differences between agro-ecological zones and land use types. The results show that pods from the Lake Victoria Crescent zone and fallow land use type were significantly longer, larger in breadth, and heavier than those from other zones and land use types ($P<0.005$). There were more seeds per pod in the samples from West Nile zone than other zones. The morphological values were found to be higher than those recorded in most studies carried out elsewhere. The differences between agro-ecological zones are a reflection of the different agro-climatic and soil conditions of Uganda. These morphological differences expressed in genetic variations will be very useful for promoting domestication and commercialisation of *T. indica* in Uganda.

Key words: land use type, wild fruit trees, morphology, *T. indica*

4.1 Introduction

Tamarindus indica (syn. *T. occidentalis* Gaertn.; *T. officinalis* Hook.) occurs widely throughout tropical Africa around homesteads and in the wild (El-Siddig *et al*., 2006). It is a pan-tropical fruit tree frequently associated with shrubs, deciduous thickets and termite mounds (Parrotta, 1990). It is a legume and has nodule like lumps on the roots, but does not appear to fix nitrogen (NRC, 2008). It grows in a wide range of climatic conditions and is highly drought tolerant. It thrives where annual rainfall drops as low as 750 mm (sometimes below 500 mm) and up to an elevation of 1,500 m elevation (NRC, 2008).

In Uganda, *T. indica* is found in Lake Victoria Crescent, Eastern, Mid Northern, West Nile and Karamoja dry lands agro-ecological zones (GoU, 2004; Katende *et al*., 1999). It is widely used locally for food and income generation. Uganda, just like other *T. indica* producing countries in Africa has not developed the *T. indica* agro-processing industries. This industry would provide the ready made products for local markets and export.

Ascertaining information on morphological characteristics of *T. indica* would be useful partly in promoting the consumption, domestication, protection, commercialisation and development of the local industries for indigenous fruit trees. As *T. indica* trees are not grown in all agro-ecological zones in Uganda, thus, this study was undertaken, and clarified whether *T. indica* stands in the in different agro-ecological zones of Uganda differ in the selected morphological characteristics.

4.1.1 Aim

The aim of the study was to examine the variation by land use types in morphological characteristics of *T. indica* pods sampled from each of the selected three agro-ecological zones in Uganda.

4.1.2 Hypothesis

Ho: There are no differences in the morphological characteristics of *T. indica* pod across all the selected agro-ecological zones in Uganda.

4.2 Materials and Methods

4.2.1 Research Design

Ideally, the sampling sites should be chosen over 300 kilometres grid as a function of the ecological gradient of the area in order to take into account the differences in climate or ecology (Palmberg, 1985). However, the agro-ecological zones are located less than 300 km apart and thus each zone was chosen from over 200 km from each other. Each zone was stratified into two major land use types: crop fields and fallows. The crop fields were current farms of agricultural crops while the fallows were former fields that had not been cultivated for at least five years prior to the study.

Twelve sites (sub-counties), with *T. indica* trees were selected (four sub-counties per district and covering 5 - 7 km^2). A total of 20 trees was selected from each land use type in each zone. Five trees with fruits were selected from each land use type in each sub-county. Selection criteria included ease of access, good tree health (absence of obvious signs of disease and fire), and presence of pods. The sample trees were located about 200 meters apart (trees close to each other were not selected as they were considered to be having similar origin / genetic characteristics).

The pods were collected during the fruit harvesting season (from December 2007 to March 2008). The canopy of each sample tree was divided into three levels: top, middle and bottom. The trees were climbed using ladders to collect ripe pods (selected by gently squeezing). Ripe pods were considered to be those with scurfy brown, woody, fragile shell with brown pulp and blackish-brown, and hard shiny seeds (Hernandez-Unzon and Lakshminarayana, 1982).

Eight pods were collected from each canopy level (two from each of the cardinal compass directions). In total, 24 pods were harvested from each tree following the method of Jøker (2000). A total of 480 pods were therefore, harvested from 20 trees per land use type, giving 960 pods per zone (district) and 2,880 pods for the two land types in each agro-ecological zone. Pods collected from each tree were pooled, kept in white polythene bags and labelled according to tree number and canopy level (T_1C_1, T_1C_2, and T_1C_3). The pods were taken to the laboratory at Makerere University, Faculty of Forestry and Nature Conservation for various measurements.

4.2.2 Measurement of Morphological Characteristics of Pods and Seeds

The pods were washed with distilled water and allowed to dry for one hour after which the following parameters were determined: length (cm), breadth (cm), individual pod total mass (g), seed mass (g), pulp mass (g) and number of seeds. Length of pod (LoP) was determined as the distance from the panicle to the end of pod on the outer surface (measured with the help of a thread). Breadth of pod (BoP) was determined by taking an average of the two breadth measurements using a vernier calliper. Pulp mass was obtained by weighing the pulp (using an electric weighing scale to 99% accuracy) after removing the seeds. To determine seed mass, seeds (manually removed from the pod) were counted and weighed. Decomposing pulp and seeds damaged by insects were excluded from the samples after measurement (Jøker, 2000). This was done to avoid contaminating clean samples. Depulping of pods was done using a pair of scissors.

4.2.3 Data Analyses

Each of the pod and seed samples were aggregated by land use type and agro-ecological zone. The means for each parameter were computed and analyses were carried out to investigate relationships between land uses and agro-ecological zones. Two-way analysis of variance (ANOVA) was carried out (using SPSS version 10.0 for windows) to test differences in morphological characteristics of pods between agro-ecological zones and land uses. The least significant difference (LSD) in a post hoc test was used to separate means using the general linear model for post hoc multiple comparisons of observed means. The Pearson Correlation coefficient was calculated to determine the relationship between morphological characteristics.

4.3 Results

4.3.1 Morphological Characteristics of *T. indica* According to Agro-ecological Zones of Uganda

The disaggregated data for the different agro-ecological zones of Uganda show that there were differences in morphological characteristics across the different agro-ecological zones of Uganda. The minimum, maximum, mean, standard deviation and standard error shows significant difference across the agro-ecological zones (Table 4.1). The samples from the Lake Victoria Crescent agro-ecological zone had the lowest minimum pod length value (1.2 cm) while West Nile zone had highest maximum value (29.80 cm). The mean and standard deviations were also highest at West Nile agro-ecological zone (15.12±2.07).

Table 4.1. Desegregated Morphological Characteristics of *T. indica* According to Agro-ecological Zone

Variables	**Minimum**			**Mean±SD**			**Maximum**			**SE**		
	LVC	East	WN	LVC	East	WN	LVC	East	WN	LVC	East	WN
Pod Length	1.20	10.20	12.90	8.38±1.28	11.58±0.75	15.12±2.07	10.20	12.90	29.80	0.04	0.02	0.07
Pod Breath	1.10	1.15	1.25	1.98±0.30	1.79±0.27	1.870.±0.20	7.05	2.60	2.70	0.01	0.01	0.01
Total Pod Mass	1.43	2.38	1.97	14.30±7.35	13.63±6.06	13.17±5.29	56.84	45.64	32.48	0.24	0.20	0.17
Total Seed No.	1.00	1.00	1.00	5.59±2.81	5.95±2.74	6.53±2.78	15.00	17.00	14.00	0.09	0.09	0.09
Total Seed Mass	0.07	0.08	0.20	4.22±2.53	3.41±1.87	3.88±2.09	17.05	11.92	12.16	0.08	0.06	0.07
Pulp Mass	0.05	0.87	0.27	4.58±2.84	5.33±2.75	5.24±2.42	22.04	19.50	15.81	0.09	0.09	0.08

4.3.2 Morphological Characteristics of *T. indica* in Different Agro-ecological Zones of Uganda

Results of morphological characteristics in the three different agro-ecological zones show various differences between agro-ecological zones (Tables 4.2 and 4.3). The aggregated data for the different agro-ecological zones show.

Table 4.2. Aggregated Morphological Characteristics of *T. indica* in Different Agro-ecological Zones of Uganda

Aggregated Characteristics	**Minimum**	**Mean±SD**	**Maximum**	**SE**
Pod Length (cm)	1.2	11.69±3.12	29.80	0.058
Pod Breath (cm)	1.1	1.88±0.27	7.05	0.005
Total Pod Mass (g)	1.43	13.70±6.31	56.84	0.118
Total Seed No.	1.00	6.02±2.80	17.00	0.052
Total Seed Mass (g)	0.07	3.84±2.21	17.05	0.041
Pulp Mass (g)	0.05	5.05±2.70	22.04	0.050

4.3.3 Morphological Characteristics of *T. indica* Pods and Seeds

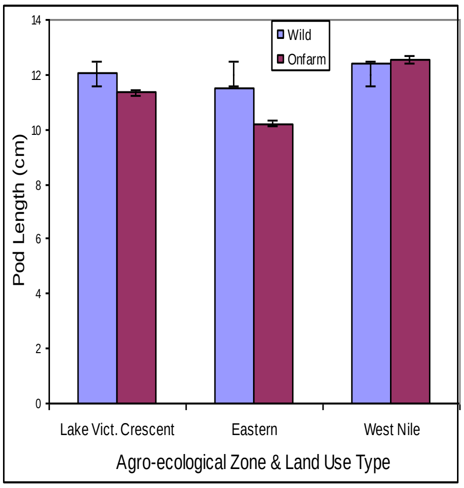
There were substantial differences in morphological characteristics of *T. indica* pods and seeds between agro-ecological zones and land use types (Table 4.3). Overall, all morphological characteristics showed significant differences between agro-ecological zones. Length and breadth of pods as well as pulp mass were significantly different between land use types. The Lake Victoria Crescent samples had higher mean values than the rest of the samples. Additionally, samples from the fallow land use type in general had higher values than samples collected from the onfarms (P<0.005).

Table 4.3 Characteristics of *T. indica* from the Different Agro-ecological Zones and Land Use Types in Uganda

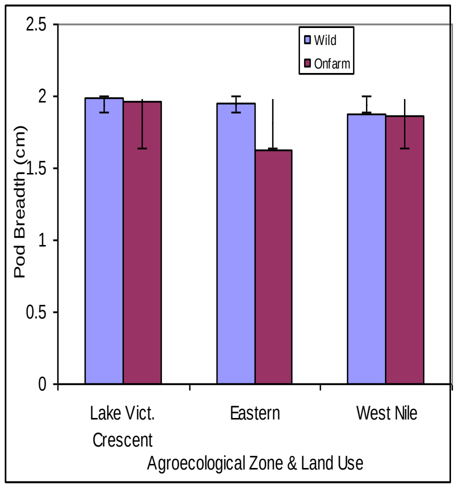
Characteristics of Pods and Seeds	**Morphological Main Factors**				
	Agro-ecological Zone			Land use	
	LVC	Eastern	West Nile	Wild	Onfarm
Pod Length (cm)	11.7[a]	10.9[b]	12.5[c]	12.0[a]	11.4[b]
Pod Breath (cm)	2.0[a]	1.8[b]	1.9[c]	1.9[a]	1.8[b]
Total Pod Mass (g)	14.3[a]	13.6[b]	13.2[b]	13.8[a]	13.6[a]
Total Seed No.	5.6[a]	6.0[b]	6.5[c]	5.9[a]	6.1[a]
Total Seed Mass (g)	4.2[a]	3.4[b]	3.9[c]	3.8[a]	3.9[a]
Average Seed Mass (g)	0.8[a]	0.6[b]	0.6[b]	0.6[a]	0.6[a]
Pulp Mass (g)	4.6[a]	5.3[b]	5.2[b]	5.2[a]	4.9[b]

Same superscript letters in each row indicate no significant differences between means of the respective agro-ecological zones and land use types ($P < 0.005$)

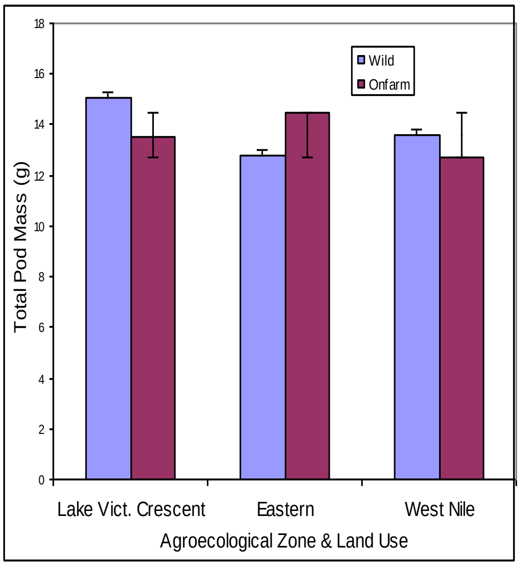
In general, the differences in values of morphological characteristics of pods and seeds between land use types in different agro-ecological zones showed that the samples from the Lake Victoria Crescent zone had higher values compared to other zones. Additionally, further analyses also show the differences in the interactions between agro-ecological zones, land use types and different pods and seeds' characteristics which were not easily explained above (Figure 4.1).



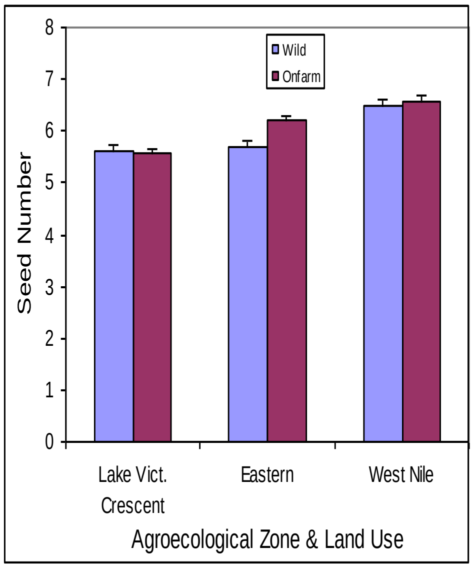
(a) Pod length interactions with agro-ecological zone & land use



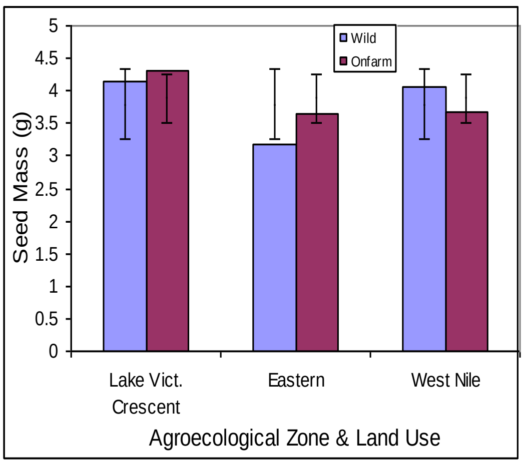
(b) Pod breadth interactions with agro-ecological zone & land uses



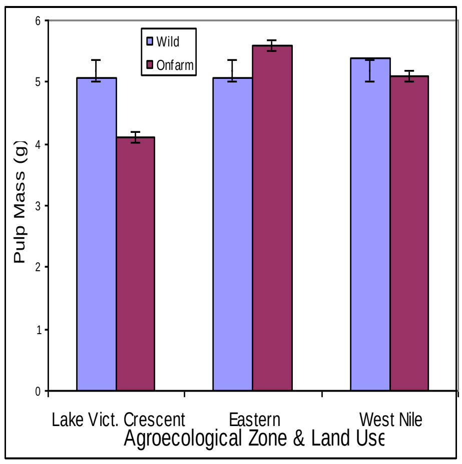
(c) Total pod interactions with agro-ecological zone & land use



(d) Seed numbers' interactions with agro-ecological zone and land use



(e) Seed mass interactions with agro-ecological zone & land use



(f) Pulp mass interactions with agro-ecological zone & land use

Figure 4.1. Variations of morphological characteristics of *T. indica* pods and seeds between land use types in the different agro-ecological zones of Uganda

There were positive correlations between all characteristics of pods and seeds in the samples from different agro-ecological zones and land use types as indicated in Table 4.4.

Table 4.4 Pearson's Correlation (R) Relationships between *T. indica* Pods and Seeds Characteristics

	Fruit Length	Fruit Breadth	Total Fruit Mass	Seed Number	Seed Mass
Fruit Breadth	0.312**				
	(0.000)				
Total Fruit Mass	0.733**	0.452**			
	(0.000)	(0.000)			
Seed Number	0.548**	0.104**	0.603**		
	(0.000)	(0.000)	(0.000)		
Seed Mass	0.504**	0.297**	0.715**	0.779**	
	(0.000)	(0.000)	(0.000)	(0.000)	
Pulp Mass	0.542**	0.358**	0.724**	0.536**	0.547**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Pearson correlation (R) are indicated by upper values, ** indicate correlations, P values ($P<0.01$)

4.4 Discussion

The differences in mean breadth of pod, pod mass, total seed number and total seed mass by both agro-ecological zone and land use type indicates the influence of agro-ecological zones and land use types on morphological characteristics. The observations could be due to substantial effects of the environmental factors and land use factors (El-Siddig *et al.*, 2006; Haynes *et al.*, 2006). The West Nile agro-ecological zone had higher morphological values than other zones probably due to the agro-ecological zones and the soil factors. In addition, West Nile agro-ecological zone, receives highest rainfall than other studied agro-ecological zones, which encourages the production of longer and wider pods.

In Kenya, studies by Chiteva and Kituyi (2006) reported the *T. indica* pods in different agro-ecological zones had different mineral contents and different fruit ripening time showing an influence of the agro-ecological factors. Different agro-ecological zones studied have different environmental factors such rainfall patterns, soils types and formation, major geological formation, temperatures, vegetation types. The difference within the same zone could be due to differences in land uses (such as onfarms and fallows), where the *T. indica* fruits had been sampled.

The high Pearson's Correlation (R) observed among the various pod characteristics could be attributed to close association of the morphological variables (Hossain and Abdul, 2007). The agro-climatic factors (such as rainfall totals and distribution), soils (productivity, fertility and management conditions), topography, temperatures, moisture content and vegetation cover could have been responsible for promotion of the superiority of characteristics of trees on the fallow land use type. The variations of the different parameters observed between the sites could also be attributed to human activities given the fact that some *T. indica* plants were found close to human activities such as settlements, although it was difficult to differentiate the qualities with those in fallows. The differences expressed in morphological traits of *T. indica* from the different agro-ecological zones of Uganda could mean that it has high genetic differences to be exploited.

4.5 Conclusion

Differences were observed among morphological characteristics of *T. indica* population from different agro-ecological zones and land use types in Uganda. These differences are probably caused by differences in land uses and their management systems. The samples from Lake Victoria Crescent zone and fallow land use type recorded higher morphological characteristic values than the samples from other zones and land use types. These morphological characteristics' differences are a reflection of the extensive occurrence of *T. indica* in the different agro-ecological zones and land use types in Uganda.

4.6 Recommendations

The morphological characteristics exhibited by the Ugandan *T. indica* make it possible for the investigations of the different morphological characteristics from the different agro-ecological zones, land use types and its management systems in respect to the environmental and climatic factors. Morphological differences in genetic variations expressed can be useful in promoting domestication and onfarm conservation across the production and non production agro-ecological zones in Uganda.

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CHAPTER FIVE

EVALUATION OF MINERAL COMPOSITION OF *TAMARINDUS INDICA* PULP AND SEEDS IN DIFFERENT AGRO-ECOLOGICAL ZONES IN UGANDA

Abstract

The mineral composition of *T. indica* pulp and seeds were evaluated from three agro-ecological zones in Uganda (Lake Victoria Crescent, Eastern and West Nile). The aim was to compare the mineral composition of *T. indica* pulp and seeds from the different agro-ecological zones and land use types. Separately grounded samples of pulp and seeds were sun dried and analysed for Zn, Fe, Mg, P, Na, K and Ca. The univariate analysis of variance in the General Linear Model was used to analyse the differences. Treatment means were separated using the Least Significant Difference (LSD) in Post Hoc Tests. The results show that there were significant differences in mineral composition levels of pulp and seeds between agro-ecological zones with the exception of phosphorus. The samples from Lake Victoria Crescent zone, as well as fallow land use type had higher mineral levels. All the seed samples had higher mineral levels than the pulp. The *T. indica* seeds (which are usually thrown away after depulping) contain more minerals than pulp samples, and should be promoted as livestock feeds and sources of minerals for humans. Whereas *T. indica* individuals are now being promoted on-farms, their mineral concentrations are lower than those from the fallows.

Key words: *Tamarindus indica*, mineral composition, pod, fallow, onfarm.

5.1 Introduction

Several wild tree species bear fruits and seeds during the dry season (Nadro and Umaru, 2004), a time when households are often faced with food insecurity. During this time, these fruits are frequently consumed. According to Oliveira *et al*. (2006), fruits and vegetables provide nutrients that are important for several human body functions. Wild fruits, therefore, offer a convenient and cheap means of providing people in the tropics with adequate supplies of minerals, fat, protein and carbohydrates (Eromosele *et al*., 1991). Although wild fruits contribute to nutrition and health during the most vulnerable period of human life, data on nutritional composition of many wild fruits are not quite available (NRC, 2008). Assembling such information would thus be important for planning the diets of many rural communities.

Tamarindus indica is one of the major fruit trees growing in various parts of the world that is potentially important for supplementing diets (NRC, 2008). The interest in *T. indica* is linked to its nutritional and chemical properties. The *T. indica* fruits provide two important products - pulp and seeds, mostly eaten directly or used for making local food and drinks. The seeds, obtained after de-pulping the pod, are usually thrown away. The pulp is then used as source of supplemental food, and nutritionally balanced diets (Anupunt *et al*. 2002). In Uganda, it is used to make millet bread, porridge, juice and alcoholic beverages among many ethnic communities. Although the seeds are not consumed because the seed extraction / processing technologies are not widely available in Uganda, the production agro-ecological zones have fruits being widely sold in local markets. However, its utilisation has not been fully commercialised throughout Uganda.

Although previous studies such as that of Yusuf *et al*. (2007a) have documented the mineral composition of *T. indica* pulp and seeds, no direct attempt has been made to investigate the differences in mineral composition between agro-ecological zones and land use types. This aspect is the goal of the present study. By investigating the mineral composition of *T. indica* across the selected agro-ecological zones in Uganda, its nutrition and importance, and the need for protecting the species will be realised.

5.1.1 Aim and Objectives

The aim of this study was to evaluate the mineral composition of *T. indica* in Uganda.

The specific objectives are:

(i) to examine mineral composition of *T. indica* pulp samples from the different agro-ecological zones and land use types in Uganda,

(ii) to determine mineral composition of *T. indica* seeds samples from the different agro-ecological zones and land use types in Uganda.

5.1.2 Hypotheses

Two hypotheses were tested:

Ho. There is no difference in mineral composition of *T. indica* pulp samples from the different agro-ecological zones and land use types in Uganda,

Ho. There is no difference in mineral composition of *T. indica* seeds samples from the different agro-ecological zones and land use types in Uganda.

5.2 Materials and Methods

5.2.1 Materials

The pods were collected during the fruit ripening season between December 2007 and March 2008. The canopy of each sample tree was divided into three levels: top, middle and bottom to make sure all samples had the highest opportunity of being picked. Ladders were used to collect ripe pods (confirmed by gently squeezing) from the sampled trees. The collected samples were aggregated by agro-ecological zone and by land use type. Decomposed and damaged pulp and seeds were discarded.

After depulping, the seeds and pulp were separately sun dried for six days and later in an oven at 60°C for three days until the weight remained constant. These were then separately grounded in an electric grinding machine (Brooks Crompton, 2000 series - UK) to 60 mm mesh size based on agro-ecological zones and land use types. The powdered samples were stored in plastic containers at room temperature for further laboratory analyses at the Departments of Food Science and Technology as well as Animal Science laboratories in Makerere University. The samples were later analysed for zinc (Zn), iron (Fe), Magnesium (Mg), Phosphorus (P), sodium (Na), Potassium (K) and calcium (Ca) according to Association of Official Analytical Chemists, AOAC (1999) procedures.

5.2.2 Mineral Assays

Duplicate 0.5g pulp and seed samples were placed in digestion tubes, and 7 ml of digestion mixture (composed of sulphuric acid, hydrogen peroxide and lithium sulphate as a catalyst) added and mixed. The mixture was heated in a block digester until the digest was clear. Heating was continued for 30 minutes to ensure that all the organic matter was digested, then allowed to cool to room temperature. All samples in the digestion tubes were transferred into 100 ml volumetric flasks and made up to 100 ml using distilled water. Portions (5 ml each) of the solution were then analysed for different minerals. The detailed analytical procedures are described in AOAC (1999).

The compositions of Zn, Fe and Mg were determined using an atomic absorption spectrophotometer (Perkin - Elmer, 2380 model) at wavelengths of 213.9, 248.3, 285.2nm, and slit of 0.7, 0.2, 0.7 nm for Zn, Fe, Mg respectively. The P composition was estimated spectrophotometricaly using Jenway UV/Vis Spectrophotometer (6405 model), calibrated at a wavelength of 400nm using blank concentrations of 0, 5, 8 and 10 (ppm). Composition of Na, K and Ca were determined using the Jenway flame photometer (model PFP 7).

5.2.3 Data Analysis

The data were entered into Microsoft Excel by agro-ecological zone, land use type and source of samples (from pulp or seeds). Univariate analyses of variance in General Linear Model were carried out using SPSS for windows version 10.0 to determine the variations in composition. Treatment means were separated using the Least Significant Difference (LSD) in the Post Hoc Test.

5.3 Results

5.3.1 Mineral Composition of *T. indica* Pulp

The composition of minerals in *T. indica* samples was generally lowest in West Nile and highest in Lake Victoria Crescent agro-ecological zones. The samples from fallows had relatively higher mineral concentrations than those from the onfarm. There were significant differences ($P<0.005$) in mineral concentrations among the agro-ecological zones with the exception of P (Table 5.1). The levels of Zn, Fe, Mg, Na, Ca were significantly higher by 31 - 60% in the samples from the Lake Victoria Crescent zone. The level of P was highest in the samples from West Nile zone (by up to 0.7%) while K was more in the samples from Eastern zone by up to 20%. The composition of minerals in the *T. indica* pulp samples was in the order: Ca>Na> Mg>K>Fe>P>Zn (Table 5.1).

Table 5.1 Mineral Composition of *T. indica* Pulp from the Different Agro-ecological Zones and Land Use Types in Uganda

Mineral Comp. – mg/100g	Agro-ecological Zone and Land Use Types: Zone			Land use		Zone * Land Use							
	West Nile	LVC	East	Aggregated Fallow	Aggregated Onfarm	LVC * Fallow	LVC * Onfarm	East* Fallow	East * Onfarm	WN* Fallow	WN* Onfarm	P: zone *land	SE: zone *land
Zn	3.3^{a}	7.9^{b}	2.9^{a}	5.0^{a}	4.4^{b}	8.7	7.1	3	2.8	3.4	3.3	0.005	0.182
Fe	15.6^{a}	37.9^{b}	13.7^{c}	20.8^{a}	24.0^{b}	36.8	38.9	14.7	12.8	10.9	20.4	0.001	0.578
Mg	84.7^{a}	99.8^{b}	95.7^{c}	104.2^{a}	82.5^{b}	110	89.5	112.6	78.8	90.1	79.2	0.001	0.34
P	13.8^{a}	13.5^{a}	13.7^{a}	13.4^{a}	13.9^{a}	0.3	0.2	0.1	0.2	0.3	0.1	0.001	0.502
Na	80.8^{a}	171.2^{b}	59.6^{c}	100.8^{a}	107.0^{a}	171	171.3	67.7	51.5	63.6	68	0.001	0.019
K	20.9^{a}	24.5^{b}	30.5^{c}	26.5^{a}	24.1^{b}	21.9	27.2	32.8	28.2	24.9	16.9	0.001	0.34
Ca	117.1^{a}	170.5^{b}	137.8^{c}	155.8^{a}	127.7^{b}	173.6	167.3	168.3	107.2	125.5	108.6	0.001	0.004

Different letters in the same row show statistically significant differences, * shows interactions.
East = Eastern, WN = West Nile, LVC=Lake Victoria Crescent.

5.3.2 Mineral Composition of *T. indica* Seeds

The compositions of different minerals in *T. indica* seeds were lowest in the samples from the Lake Victoria Crescent and highest in the samples from the West Nile zone, except K. The samples from the fallow land use type had higher values than those from onfarm, there were significant differences in all minerals analysed except P ($P<0.005$) between the agro-ecological zones (Table 5.2).

Table 5.2 Minerals Composition of *T. indica* Seeds from the Different Agro-ecological Zones and Land Use Types in Uganda

Nutrients mg/100g	Zone			Land use		Zone * Land Use						P	SE
	West Nile	Lake Victoria	East	Aggregated Fallow	Aggregated Onfarm	LVC * Fall	LVC *Onfa	East *Fall	East * Onfa	WN * Fall	WN* Onfa	Zone * land	zone *land
Zn	13.2^{a}	7.8^{b}	6.4^{c}	11.1^{a}	7.2^{b}	8.5	7.2	6.2	6.6	18.6	7.9	0.001	0.245
Fe	37.0^{a}	30.3^{b}	32.2^{c}	35.2^{a}	31.1^{b}	33.4	27.2	33.8	30.7	38.5	35.5	0.032	0.491
Mg	196.0^{a}	167.4^{b}	177.6^{c}	193.0^{a}	167.7^{b}	177.7	157	192.7	162.5	208.6	183.5	0.001	0.494
P	21.8^{a}	13.7^{b}	19.7^{c}	22.5^{a}	14.3^{b}	15.6	11.8	24.9	14.4	27.1	16.6	0.001	0.116
Na	168.4^{a}	109.1^{b}	118.1^{c}	161.3^{a}	102.3^{b}	116.6	101.5	153	83.2	214.5	122.3	0.001	0.005
K	11.3^{a}	12.7^{b}	13.9^{c}	15.4^{a}	9.9^{b}	14.8	10.5	18.1	9.7	13.1	9.4	0.001	0.01
Ca	161.1^{a}	136.1^{b}	154.0^{c}	170.5^{a}	130.3^{b}	137.2	135.1	194.2	113.7	180.1	142.1	0.001	0.005

Different letters in the same row show statistically significant differences, * shows interactions.
East = Eastern, WN = West Nile, LVC=Lake Victoria Crescent, Fall = Fallow, Onfa = Onfarm.

5.4 Discussion

5.4.1 Zn concentration

The concentration of Zn was higher in the *T. indica* seeds than the pulp samples. The fallows had higher Zn levels than onfarm. Samples from the West Nile zone had higher Zn concentrations in the seeds than the other two zones. In the case of pulp, the Zn levels were higher in the samples from Lake Victoria Crescent zone.

The Zn composition of pulp and seeds are within the ranges reported elsewhere (for other fruits also, Maranz *et al.*, 2004; Pugalenthi *et al.*, 2004). The Zn levels are, however lower than recorded elsewhere (Krithika and Radhai, 2007; Chiteva and Kituyi, 2006; Oliveira *et al.,* 2006). Zn is from the soil, stored in the plant seed and utilised for the maturation processes. Zn is also essential for the transformation of carbohydrates and regulating consumption of sugars. Under favourable climatic and soil conditions, Zn facilitate growth and development of the plant, promotes growth, starch formation and general production (Brady, 1990). The samples from the West Nile zone were from a relatively high rainfall and temperature (UDIH, 2007), and this could probably be the main reason why there is more accumulation of Zn compared to those of other zones. Differences in the land management practices could also explain the differences in the Zn levels between the land use types.

5.4.2 Fe concentration

The Fe composition in both the pulp and seed samples generally exceed levels reported elsewhere (Sena *et al.,* 1998; Yusuf *et al.,* 2007b). Although, the Fe concentration is lower than the values reported by Chiteva and Kituyi (2006) and Oliveira *et al.* (2006) it exceeds those reported by Ibironke *et al*. (2006). These high Fe concentration values indicate that the pulp and seed of *T. indica* can be a good source of Fe to enrich rations for treating Fe deficiency in humans, particularly in rural areas where *T. indica* is available in the local markets. Moreover, collection of fruits from *T. indica* stands in the fallows (with relatively higher Fe levels) should be encouraged to reduce pressure on the wild populations.

5.4.3 K concentration

The K levels in *T. indica* are higher in the pulp than seed samples. In cases, the levels are higher in Lake Victoria Crescent than the other two zones. In addition, fallow land use type had higher K levels than onfarm. Although in Nigeria, Ibironke *et al*. (2006) documented higher values of K than the result of this study, while in Brazil, Oliveira *et al.* (2006) documented lower values of K than those reported in this study. According to Brady (1990), the levels of K are usually highest under osmotic stress condition. On average, the samples from the West Nile zone had lower levels of K. This could be due to variations in amounts of rainfall, most K are suspected to have been lost due to the differences in concentrations from the *T. indica* trees into the soil.

Because K helps in the building of proteins, photosynthesis, fruit quality and reduction of plant diseases, and is obtained by plants from soil minerals, organic materials and fertilizer (Brady, 1990), their use in different plant functions results in less K in the seed than in the pulp samples. K is absorbed by plants in larger amounts than any other mineral element except N and, in some cases, Ca. As the K supply to plant roots depends mainly on the diffusion flux that a soil can maintain in the direction of plants to supply it (Brady, 1990). Soil types may also influence the amount of K that can be available in both the *T. indica* pulp and seed samples. Thus, evaluation of K in the soil at a particular time would be needed to guide the management of *T. indica* stands in relation to supply of K elements.

5.4.4 P, Ca, Mg and Na concentrations

The levels of P in *T. indica* pulp and seed samples in Uganda are generally higher than those reported by Krithika and Radhai (2007). P is required by the plants in the formation of oils, sugars, starches (Brady, 1990), while Ca is an essential part of plant cell wall structure. It provides for normal transport and retention of other elements as well as strength in the plant. The levels of Ca recorded in the present study are within the range documented by Oliveira *et al.* (2006). The Ca, Mg and Na values are similar to those documented by Krithika and Radhai (2007) indicating that *T. indica* from Uganda have sufficient qualities for mineral exploitation.

In general, most minerals produced by the plants are stored in seeds, leading to the higher mineral levels in seeds than pulp. Stored minerals and few agricultural practices in the fallow land use type, probably promote retention of more P. The differences in climate, elevation and soils between the agro-ecological zones are sufficiently great that the mineral differences are probably attributed to it. In addition, evaluation of the genetic differences between individual in the different agro-ecological zones could contribute to clear understanding of the differences observed. More retention of minerals in seeds observed in the in the West Nile zone could be related to high amount of rainfall in the zone. As reported by Maranz *et al*. (2004), levels of major minerals in fruit trees can be twice in higher rainfall zones than in other zones with lower rainfall.

5.5 Conclusion

The study shows that there are significant differences in mineral composition levels recorded between the agro-ecological zones and land use types in Uganda. The *T. indica* from the Lake Victoria Crescent zone, as well as fallow land use type had significantly higher mineral levels than those found in other zones and elsewhere. It was also noted that, the *T. indica* seeds samples which are usually thrown away after depulping and taking away the pulp, contain more minerals than pulp samples itself indicating that there are untapped potentials in the use of seeds as a source of minerals. The consumption of *T. indica* seeds could therefore be promoted and developed as a good source of minerals in all the agro-ecological zones and land use types although its quality need to be ascertained.

5.6 Recommendations

Educating the local people within the production agro-ecological zones on the use of both *T. indica* pulp and seeds should be carried out. More research emphasis needs to be put on the seeds of *T. indica* occurring on fallow and Lake Victoria Crescent zone that had higher concentrations. Whereas the *T. indica* individuals found onfarm can be promoted for consumption, the mineral concentrations are low implying that tree improvement with the fallow population should be encouraged. The relatively high level of ash in the samples is an indication that *T. indica* can also be incorporated in the diet of humans and livestock. Since the *T. indica* seeds contain more minerals than the pulp samples, consumption of *T. indica* seeds should be widely promoted.

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CHAPTER SIX

PROXIMATE AND PHYSICO-CHEMICAL COMPOSITION OF *TAMARINDUS INDICA* PULP AND SEEDS IN UGANDA

Abstract

The proximate and physico-chemical composition of *T. indica* pulp and seeds from different agro-ecological zones and land use types in Uganda was investigated in 2008. The aim of the study was to analyse the proximate and physico-chemical composition of *T. indica* in Uganda. The results show that samples from Lake Victoria Crescent zone and the fallow land use type are rich in moisture content, protein and crude fibre. These show that *T. indica* from Uganda are rich in proximate contents compared to studies elsewhere. Consumption of *T. indica* in non-producing agro-ecological zones should be promoted as they are good for health. The relatively high level of ash in both the pulp and seeds is an indication that *T. indica* can also be incorporated in the diet of diabetic and antheroclerotic patients, also being an attractive feed for non-ruminants. Thus, immediate programme that will encourage the retention, protection and trials for planting of *T. indica* trees in these agro-ecological zones and beyond should be enforced. The influence of environmental factors, agro-ecological zones and land use types on the proximate and physico-chemical composition also needs to be investigated for a better understanding.

Key words: land use, proximate, wild, onfarm, *T. indica*

6.1 Introduction

Edible wild plants contribute immensely to the micronutrient nutritional requirements of rural populations (Freiberger *et al*., 1998). Besides, the legumes (many of which are wild) are major sources of plant protein, fats and essential amino acids (Yusuf *et al*., 2007b).

Some of the small fruits that are nutritionally rich can also provide benefits when the rest of the diet is deficient in vitamins and minerals (NRC, 2008). Although the nutritional values of legumes are of great importance (Ahmed *et al.,* 2006), there is a search for dietary constituents with benefits beyond those ascribed to the macro and micronutrients (Das *et al.,* 2005). This therefore necessitated the assessment of the proximate and physico-chemical composition of *T. indica*.

According to Yusuf *et al*. (2007a), the proximate composition is generally higher in seed than pulp in particular, the ash content (which is an indicator of mineral contents), is lower in pulp than in seeds. This shows that the seed contains relatively large amounts of some mineral elements than the pulp. *Tamarindus indica* LINN, (one of the leguminous native trees to East Africa), has been cultivated in the tropics and subtropics for many years (Morton, 1987). It is extensively used by smallholder farmers in human diet (El-Siddig *et al*., 2006). The nutritional properties and an increasing domestic demand for the *T. indica* fruits thus provide an excellent scope for the extension of its cultivation.

Up to half the pod weight of *T. indica* consists of pulp, which contains sugars and tartaric organic acids (NRC, 2008). The acidity is largely due to tartaric acid, whose level sometimes is about 12% by weight of the pulp. Although the high acidity might suggest a good antiscorbutic, numerous tests have found that both ripe and green stages contain smaller quantities of vitamin C (NRC, 2008). The pulp of *T. indica* is also reported to be richer in sugar than any other fruit (30-40%).

While very few studies have been carried on the proximate and physico-chemical composition of *T. indica* (NRC, 2008), information available on *T. indica* is also not directly related to the proximate and physico-chemical studies. Moreover, there is need to also document the relationship of proximate and physico-chemical values with agro-ecological zones and land use types. This study assessed the proximate and physico-chemical properties of *T. indica* pulp and seeds from the different agro-ecological zones in Uganda. The information generated can thus be used to create public awareness of dietary benefits and nutritional contents of *T. indica* for human consumption, industrial uses and for animal feed formulation.

6.1.1 Aim and Objectives

The aim of the study was to analyse the proximate and physico-chemical composition of *T. indica* in Uganda.

The specific objectives were to:

(i) determine the proximate composition of *T. indica* pulp and seeds from different agro-ecological zones and land use types in Uganda,

(ii) ascertain the physico-chemical composition of *T. indica* pulp and seeds from different agro-ecological zones and land use types in Uganda.

6.1.2 Hypotheses

The hypotheses tested were:

(i) there is no difference in proximate composition of *T. indica* pulp and seeds between agro-ecological zones and land use types,

(ii) there is no difference in physico-chemical composition of *T. indica* pulp and seeds between agro-ecological zones and land use types.

6.2 Materials and Methods

6.2.1 Sampling Design and Preparation of Samples

The evaluated pods and seeds used for morphological characteristics measurements were later used for the analysis of proximate and physico-chemical characteristics. The samples were aggregated by agro-ecological zone and land use type and separately grounded into powder.

6.2.2 Methods of Proximate Analyses

The powders from pulp and seeds of *T. indica* samples were separately analysed for: moisture content (%), total ash (%), crude oil (%), crude protein (%), crude fibre (%), total carbohydrate (%), β-carotenoids and vitamin C. The moisture content was determined by weighing samples accurately using an electric weighing scale to 99% accuracy (AOAC, 1999). The ash, crude oil and crude fibre contents were determined according to procedures in AOAC (1999). While the Kjeldhal method (AOAC, 1999) was used to determine crude protein. Total carbohydrate (%) was determined using the following formula; Total carbohydrate = 100 - (∑ % of moisture content, ash, protein, lipid, fibre), following Adepoju and Oyewole (2008) and Das *et al*. (2005). The β-carotenoids were analysed under subdued light (Rodriguez-Amaya and Kimura, 2004), and vitamin C was determined using titration method (AOAC, 1999).

6.2.3 Oil Extraction and Physico-chemical Analysis

Oil was extracted using soxlet methods (AOAC, 1999). The acid (g/mg) and peroxide (mEq/kg) were determined using rancidity methods of analysis (Kirk and Sawyer, 1989).

6.2.4 Data Analyses

Univariate analysis of variance in General Linear Model was used to determine differences in proximate and physico-chemical characteristics. Treatment means were separated using the Least Significant Difference (LSD) in Post Hoc Tests.

6.3 Results

6.3.1 Proximate Composition of *T. indica* Pulp

Proximate composition values are higher in the samples from the Lake Victoria Crescent than those from the other two zones. The samples from fallow land use type had higher proximate values than the samples collected onfarm land use type. There were differences between agro-ecological zones in the proximate variables except protein and crude fibre. Moisture contents, fibre, oil and carbohydrates samples were not significantly ($P<0.005$) within the agro-ecological zones and land use types (Table 6.1).

Table 6.1 Proximate Composition of *T. indica* pulp in Uganda

Factor	Zone			Land use		Zone * Land Use						P	SE
	West Nile	LVC	Eastern	Wild	Onfarm	LVC* Fallow	LVC* Onfarm	East *Wild	East* Onfarm	WN *fall	WN* Onf	zone* land	zone *land
MC	27.4^{a}	31.6^{b}	27.8^{a}	28.7^{a}	29.2^{a}	31.1	32.1	27.5	28	27.5	27.4	0.441	0.401
Ash	2.3^{a}	2.2^{b}	2.4^{a}	2.3^{a}	2.3^{b}	2.1	2.3	2.3	2.5	2.4	2.2	0.007	0.038
Prot.	15.7^{a}	16.1^{a}	15.7^{a}	15.9^{a}	15.7^{a}	15.7	16.5	16.5	14.8	15.5	15.9	0.008	0.28
Fibre	7.1^{a}	8.4^{a}	7.6^{a}	7.4^{a}	8.0^{a}	9.3	7.6	6.8	8.4	6.8	8.4	0.048	0.602
Oil	0.28^{a}	0.27^{a}	0.29^{a}	0.30^{a}	0.26^{a}	0.3	0.24	0.3	0.28	0.3	0.26	0.952	0.06
CHO	56.2^{a}	50.2^{b}	55.1^{a}	54.2^{a}	53.4^{a}	50.1	50.2	56.2	53.9	56.4	56	0.521	1.039

MC, moisture content; CHO, carbohydrates; Prot., protein. * = interactions between land uses and agro-ecological zones with variables, same superscript letters within a column shows no significant difference.

6.3.2 Proximate Composition of *T. indica* seed

Only moisture content, oil and carbohydrates showed significant differences in seeds between the agro-ecological zones and there were no significant differences in proximate composition of *T. indica* samples between the land use types (Table 6.2).

Table 6.2 Proximate Composition of *T. indica* Seeds in Uganda

Factor	Agro-ecological zone			Land Use Types		Agro-ecological zone*Land Use						P	SE
.	WN	LVC	East	Aggregated Fallow	Aggregated Onfarm	LVC * Fall.	LVC * Onf	East* Fall	East* Onfa.	WN* Fall.	WN* Onfa.	zone *land	zone *land
MC	9.0[a]	13.9[b]	13.2[b]	12.4[a]	11.6[a]	15.7	12.1	12.7	13.5	8.9	9.2	0.001	0.335
Ash	4.6[a]	4.7[a]	5.0[a]	4.6[a]	5.0[a]	4.4	5	4.3	5.7	5	4.2	0.017	0.267
Prot.	4.5[a]	4.9[a]	4.3[a]	4.8[a]	4.3[a]	4.8	4.9	4.9	3.8	4.7	4.3	0.154	0.299
Fibre	9.0[a]	8.6[a]	8.0[a]	8.7[a]	8.4[a]	9.1	8.1	7.2	8.9	9.9	8.1	0.109	0.748
Oil	2.98[a]	2.98[a]	2.64[b]	2.83[a]	2.91[a]	2.98	2.99	2.7	2.59	2.81	3.15	0.129	0.097
CHO	61.0[a]	56.2[b]	58.0[b]	57.9[a]	59.0[a]	54.5	58	58.6	57.6	60.5	61.5	0.424	1.177

MC, Moisture content; CHO, carbohydrates; Prot., protein, * = interactions between land uses and agro-ecological zones with variables, same superscript letters within a column shows no significant difference.

6.3.3 Physico-chemical Composition of *T. indica* Pulp

The physico-chemical composition values of *T. indica* were highest in the samples from the West Nile zone than those from other two zones. The fallow land use type had higher phyico-chemical values than the onfarm samples. There were differences between agro-ecological zones in the physico-chemical values with those samples from the West Nile zone in particular had significantly ($P<0.005$) higher vitamin C values than those from the other zones (Table 6.3).

Table 6.3 Physico-chemical Composition of *T. indica* pulp in Uganda

Factor	Zone			Land use		Zone * Land Use						P	SE
	West Nile	LVC	Eastern	Wild	Onfarm	LVC* Fallow	LVC* Onfarm	East *Wild	East* Onfarm	WN *fall	WN* Onf	zone* land	zone *land
Vit. C	201.7[a]	138.4[b]	154.6[c]	189.4[a]	140.4[b]	140.5	136.3	157.8	151.4	270	133.3	0.001	4.514
Carot.	0.16[a]	0.14[b]	0.17[c]	0.14[a]	0.17[b]	0.15	0.12	0.16	0.18	0.11	0.21	0.001	0.001

Vit. C, Vitamin Carot; Beta carotenoids, * = interactions between land uses and agro-ecological zones with variables, same superscript letters within a column shows no significant difference.

6.3.4 Physico-chemical Composition of *T. indica* Seed

The physico-chemical properties of *T. indica* seeds showed significant differences between the samples from different agro-ecological zones. The samples from eastern zone had generally higher values than those from other zones (Table 6.4).

Table 6.4 Physico-chemical Composition of *T. indica* Seeds in Uganda

Factor	Zone			Land use		Zone * land use						P	SE
	West Nile	LVC	East	Fallow	Onfarm	LVC * Fallow	LVC * Onfarm	East* Fallow	East* Onfarm	WN* Fallow	WN* Onfarm	zone *land	zone *land
Vit C	103.2^{a}	85.1^{b}	104.8^{a}	106.2^{a}	89.2^{b}	88.1	82	132	77.8	98.5	107.8	0.001	4.484
Carote.	0.13^{a}	0.24^{b}	0.33^{c}	0.20^{a}	0.27^{b}	0.16	0.32	0.32	0.34	0.13	0.13	0.001	0.001
Calori	280.9^{a}	265.0^{b}	267.8^{c}	269.0^{a}	273.4^{b}	257.7	272.3	272	263.4	277.2	284.6	0.001	0.026
Acid	10.0^{a}	19.3^{b}	19.5^{c}	18.8^{a}	13.7^{b}	23	15.5	25.1	13.8	8.4	11.7	0.001	0.029
Pero	200.3^{a}	235.1^{b}	111.0^{c}	208.8^{a}	155.5^{a}	353.8	116.4	148	74.1	124.8	275.9	0.001	0.008

CHO, carbohydrates; Vit. C, Vitamin C; Carote., beta carotenoids; Calori, calorific value; Acid, acid value; Pero, peroxide value. * = interactions between land uses and agro-ecological zones with variables, same superscript letters within a column shows no significant difference.

6.4 Discussion

6.4.1 Moisture contents

Relatively higher moisture content was recorded in the samples from the Lake Victoria Crescent zone compared to other zones. This is probably due to the rainfall patterns received in the different agro-ecological zones. While Chiteva and Kituyi (2006) and El-Siddig *et al*. (2006) also documented moisture content values within the range of this study, Manjunath *et al*. (1991) and Parvez *et al*. (2003) recorded lower values. Even then, Krithika and Radhai (2007) and Pugalenthi *et al*. (2004) documented values of moisture content that are higher than the one in this study. Although the high moisture content in a sample is an indication of its freshness (Tressler *et al*., 1980), it may also be attributed to the protective and hard nature of the pod and seeds to prevent excessive moisture loss (Yusuf and Laisi, 2006). Continued rainfall delays fruit ripening. Unpredictable changes in rainfall patters in the agro-ecological zones could have influenced the drying of fruits from the different agro-ecological zones as seen from Lake Victoria Crescent.

6.4.2 Ash content

The ash content in any sample represents total content of minerals in a food. In this study, the ash content ranges between 2.2 - 5.0. These values are within the range of values documented elsewhere such as El-Siddig *et al*. (2006), Chiteva and Kituyi (2006) and Parvez *et al*. (2003). Krithika and Radhai (2007), Yusuf *et al*. (2007b), Pugalenthi *et al*. (2004), Manjunath *et al*. (1991) however, recorded lower values than those reported by Siddhuraju *et al*. (1995). The variation may be attributed to the differences in environmental factors.

6.4.3 Crude proteins

The protein level was higher (about 4 times) in the pulp than the seed samples. These values exceed values documented by Andriamanantena *et al*. (2007), Krithika and Radhai (2007), Chiteva and Kituyi (2006) and Manjunath *et al*. (1991) but lower than those documented by Yusuf *et al*. (2007a), Parvez *et al*. (2003). The differences in crude protein values are probably associated with differences in environmental conditions in different agro-ecological zones.

6.4.4 Oil content

The oil content (about 3%) in pulp sample is relatively low. The seeds had higher oil contents (more than 10 times) than that of pulp. This is attributed probably to environmental conditions and genetic variations. The values of crude oil recorded during the present investigation were lower than those reported earlier in the same species (Krithika and Radhai, 2007; Yusuf *et al*., 2007a; Ibironke *et al*., 2006; Siddhuraju *et al*., 1995; Pugalenthi *et al*., 2004; Bhattacharya *et al*., 1994). While other studies (Chiteva and Kituyi, 2006) documented lower values, studies by El-Siddig *et al*. (2006), Krithika and Radhai (2007), Parvez *et al*. (2003) reported higher values compared to that obtained in the study. According to Maranz and Weisman (2003), high elevations and cool temperatures are associated with the high levels of oil in fruit trees. In agreement to the literatures and the present study on the oil contents, *T. indica* does not qualify as supplement to some conventional oil seeds such as ground nuts, soybeans due to its low oil contents.

6.4.5 Carbohydrates

The seed had higher levels of carbohydrates than the pulp which are within the range of earlier reports (Yusuf *et al*., 2007a; Krithika and Radhai, 2007; El-Siddig *et al*., 2006; Chiteva and Kituyi, 2006) but are lower than those reported elsewhere in Asia by Parvez *et al*. (2003) and higher than in the present study (Siddhuraju *et al*., 1995; Manjunath *et al*., 1991). In a study by Charrondiere *et al*. (2004), both available and unavailable carbohydrates have been reported. Since the unavailable carbohydrates are considered as dietary fibre, their presence in the Ugandan samples show that the *T. indica* fruits and seeds are good sources of carbohydrates (Yusuf *et al*., 2007b).

According to Charrondiere *et al*. (2004), throughout the world, use of different sets of energy conversion factors as well as different nutrient definitions can both have impacts on the energy values of foods and energy intake calculations. A case in point is a report by Siddhuraju *et al*. (1992) who reported the multiplication of crude protein, crude lipid and NFE or crude carbohydrate contents by factors of 16.7, 37.7 and 16.7 respectively. Since *T. indica* can be used to supplement carbohydrates on their own compared to other foods, it can be promoted in Uganda and beyond.

6.4.6 Crude fibre

The value of crude fibre reported in this study was higher than values recorded by Yusuf *et al*. (2007a) and Parvez *et al*. (2003) but are within those reported by Chiteva and Kituyi (2006). Since consumption of dietary fibre is important for optimal health (Burubai *et al*., 2008), foods with high fibre content such as *T. indica* are considered good for diabetic patients (Anderson, 1986; Osilesi *et al*., 1997), consumption of such foods are also encouraged for the reduction of blood cholesterol (Liu *et al*., 2000). Even then, the values of crude fibre recorded in this study are below the recommended dietary allowance in children and lactating mothers (19-25 and 29%) respectively (Ishida *et al.*, 2000) and thus may not be a good source of fibre on their own especially for children.

6.4.7 Beta carotenoids

Generally, pulp and seeds of *T. indica* are not rich in beta carotenoids. This is attributed partly to their non-green colouration (Adepoju and Karim, 2004; Edem *et al*., 1984). Although the relative proportions of carotenoids in *T. indica* are fairly constant, the absolute concentrations vary considerably. According to Rodriguez-Amaya and Kimura (2004), the composition of beta carotene in fruits and fruit vegetables is much more complex and variable, with variations even in the principal carotene. In a given pod, quantitative and qualitative differences also exists due to factors such as stage of maturity, climate / geographical site of production, cultivar/variety, plant part utilised, conditions during agricultural production, post harvest handling, processing and storage conditions.

Rodriguez-Amaya and Kimura (2004) report that maturity stage is one factor that decisively affects carotene composition, maturation of vegetables and ripening of fruits which are generally accompanied by enhanced cartenogenisis. In fruits, the carotene increase markedly both in numbers and quantity during ripening. Elevated temperatures and greater exposure to sunlight have also been reported to increase carotenogenesis in fruits (Cavalcante and Rodriguez-Amaya, 1992). Land use practices such as cultivation may also influence the carotene composition thus explaining why onfarm samples had higher values of beta carotene than fallows.

6.4.8 Vitamin C

Vitamin C in the pulp and seed samples shows higher values than earlier studies by Chiteva and Kituyi (2006). Since the variation of vitamin C content could be due to environmental factors and agro-ecological influences, cultivation of *T. indica* could be promoted especially in fallow land use type to increase its consumption for the alleviation of deficiency symptoms of vitamin C in humans.

6.4.9 Acid and peroxide values

According to Akubugwo *et al.* (2008), acid value is used as an indicator for edibility of oil and suitability for use in the paint industry. The high acid values of the oil from *T. indica* seeds, above most conventional oils (ITS, 2002) are good for human consumption. Because low acid values are not good for oil quality, storage and hydrogenation, peroxide value showed perceptible increase and are similar to values documented by Ishola *et al.* (1990), who also documented higher values than in this study. Although high values of acid and peroxide could be due to late extraction and delayed determination, they indicate the ability of *T. indica* oils to resist lipolytic hydrolysis and oxidative deterioration (Magnus, 1992).

6.5 Conclusion

The *T. indica* pulp and seeds samples' proximate and physico-chemical composition from the different agro-ecological zones in Uganda show that the Lake Victoria Crescent zone and the wild land use type are rich in proximate values. The physico-chemical values are high in the samples from the West Nile zone and in fallow land use type than those other zones and land use type. The consumption of the *T. indica* species products rich in proximate composition is thus good for both livestock and human health.

6.6 Recommendations

The relatively high level of ash documented from in pulp and seed samples show that *T. indica* can be used solely as source of ash requirements for livestock and animal diets. It could also be incorporated in the diet of diabetic and antheroclerotic patients, and as an attractive feed for livestock (non-ruminants). There is a need for further investigations into the saponification values in relation to other physico-chemical properties of the oil. Analysis of toxicity levels if undertaken, for example can guide recommendations for commercial utilisation and conservation of the species. Additional research should also be undertaken on the fatty acid profile and various bioactive compounds of the seeds in relation to human and livestock health as a way of promoting its commercialisation beyond the current production zones. Since the *T. indica* protein can supplement plant protein sources widely consumed in many rural homes, promoting consumption of *T. indica* pulp and seeds among rural communities can be a good protein supplement in the diet. Encouraging retention of *T. indica* on fallows is a good strategy as samples from the fallow land use type had the highest value of crude protein.

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CHAPTER SEVEN

GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 General Conclusion

In general, there were observed differences in morphological characteristics of the sampled *T. indica* population from the different agro-ecological zones in Uganda. The *T. indica* samples from the Lake Victoria Crescent zone and fallow land use type were significantly ($P<0.05$) longer, larger in breadth, and heavier than the samples from other zones and land use type. These morphological variations are a reflection of the extensive occurrence of *T. indica* in the different agro-ecological zones and land use types in Uganda.

The number of seeds obtained in this study, is an indication that Ugandan *T. indica* has more seeds than studies carried elsewhere. This study result reveals the needs to conserve the fallow populations of *T. indica* in the West Nile zone because the pods were heavier and longer than those from the fallow populations elsewhere in Uganda's agro-ecological zones. The higher number of seeds per pod in the samples from the West Nile agro-ecological zone than those recorded elsewhere could be related to differences in the land use types and their management systems, soil types, environmental factors, climatic and seasonal variations. Additionally, the high number of seeds indicates how important the samples are for the analysis of mineral and physico-chemical composition levels.

The mineral levels of *T. indica* samples recorded in this study indicate that the *T.indica* pod pulp samples from the Lake Victoria Crescent zone, as well as those from wild land use type had higher mineral levels than those reported from other zones and studies elsewhere although the seed samples had higher mineral levels than the pulp samples.

The proximate and physico-chemical composition levels exhibited by the *T. indica* pulp and seed samples from the different agro-ecological zones differed. As the samples from the Lake Victoria Crescent zone and the fallow land use type are rich in proximate values. It indicates that the Uganda's *T. indica* is as rich in proximate and physico-chemical values as most conventional fruits, pulps and seeds. Thus encouraging production and promoting consumption of the species products in the other production zones and onfarm could be good for both livestock and human health.

Since the ash content in any sample represents total content of minerals in food, the higher levels of ash in this study shows that it can be used solely as source of ash requirements for both human and animal consumption. The high level of ash in the seed samples and in the wild land use type is an indication that the *T. indica* seeds from fallow land use type are good sources of ash.

The physico-chemical composition levels of seed oil exhibited by *T. indica* seeds samples from all agro-ecological zones show that the seed oil has the ability to resist lipolytic hydrolysis and oxidative deterioration making it good for storage and use for various purposes, mainly commercial exploitation.

7.2 General Recommendations

A comprehensive study of the tree morphology is recommended based on agro-ecological zones and land use types in Uganda with respect to environmental, climatic and seasonal factors. The tree morphology, such as pods morphology studied are of high significance for the development of the trees for consumption, commercialisation, domestication and improvement for possible *T. indica* cultivation beyond the production zones.

The morphological characteristics differences exhibited by the samples from the different agro-ecological zones and land use types in Uganda implies that wild *T. indica* trees need to be retained for future research development, promotion for human and livestock consumption, domestication and commercialisation to beef up those on onfarms. The recommendation therefore calls for the conservation and protection of *T. indica* trees particularly in the wild land use type as the samples from the wild population has recorded more mineral concentrations compared to the samples from other land use types.

The relatively high level of ash documented from all the pulp and seeds samples is an indication that *T. indica* can not only be used as a sole source of ash requirements for human and animal consumption, but can also be incorporated in the diet of diabetic and antheroclerotic patients, including being an attractive feed for non-ruminants. This calls for the immediate programme that will encourage the retention, protection and planting of *T. indica* trees both onfarm and in the wild land use type in these agro-ecological zones and beyond.

There is a need for further investigation on the influence of agro-ecological zones, land use types and environmental factors on the observed differences in morphology, mineral composition and oil physico-chemical levels of *T. indica*. More research emphasis needs to be put on the *T. indica* occurring in the wild land use type and in the Lake Victoria Crescent zone that recorded higher values with positive promising results.

Further investigations on the physico-chemical composition of fatty acid profiles and various bioactive compounds of the *T. indica* seeds in relation to human and animal health, and the saponification values in relation to other oil physico-chemical properties of the *T.*

indica oil plus analysis of toxicity levels in the various agro-ecological zones and land use types are needed in order to guide the recommendations for commercialisation, utilisation and protection of the *T. indica* species..

The *T. indica* seeds which are usually thrown away after depulping contain more minerals than the pulp samples. Consumption of *T. indica* seeds should therefore be widely promoted. This could be done through developing further processing techniques that can be easily accessed by the rural communities who are the major user and custodian of the species.