Cordia africana (Lam.) fruit and its uses

Cordia africana (Lam.) frukt og dens bruk

Philosophiae Doctor (PhD) Thesis

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Dedication

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Abbreviations

ANOVA: ANalysis Of VAriance

AOAC: Association of Official Agricultural Chemists

AZ: Agroecological Zone

DW: Dry Weight basis

FF: Fresh Fruit off the tree on day 1

FM: conventionally processed Fresh fruit on day 7

FRAP: Ferric Reducing Antioxidant Power

FT: Traditionally processed Fresh fruit on day 7

FW: Fresh Weight basis

GAE: Gallic Acid Equivalent

HPLC: High Pressure Liquid Chromatography

HSGC: Headspace Gas Chromatography

HSGCMS: Headspace Gas Chromatography Mass Spectrometry

LU: Land Use

m.a.s.l.: meters above sea level

ml: mille litters

NDM: 2012 Dried fruit conventional,

NDT: 2012 Dried fruit traditional,

ODM: 2010 Dried fruit conventional,

ODT: 2010 Dried fruit traditional

TE: Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent

TP: Total Phenol measured with Folin Ciocalteu`s reagent

Summary

There are several underutilised and neglected species used as food in the world. These food sources are under threat of disappearing and their knowledge base being forgotten. One such plant is the *Cordia africana.* Though it grows all over Africa and the Middle East, focus on its use has been limited to its wood value. In addition to the wood value, this study has showed that it has a great potential in contributing to the overall nutrition of our society, especially as it is a tree and is known to be able to produce fruits even in drought years. This is a fruit that is locally available, cheap and easy to use, and its use value is well known by the local communities. With the climate change and the increasing human population, it is wise to conserve and promote such food sources, and make them available for a wider range of our population through improved processing and marketing.

Nutritionally *Cordia africana* was found to be a good source of total phenols. It is also a good partial source for nutritionally important vitamin A and Iron, as well as for protein, vitamin C, calcium, copper, potassium, magnesium, manganese, and phosphorus. Additionally, it was found to contain very little zinc and sodium. The physical characteristics and nutritional composition was found to vary across land use and agroecology, showing that there is a high potential for further improvement, and need for studying and selecting materials to be used for propagation.

The fruit processing study showed that the fresh fruit processing needs improvment, while fruit marketing needs further study and improvement. With the dried fruits, the cabinet drier substantially reduced the time needed for drying from 63 to 5 days, and the dried fruit processing has great potential and needs further study. The jam was also possible to make, and needs further study on processing, packaging, shelf life and marketing potential. The fruit as a whole and the processed products need promotion and marketing.

The traditional medicinal value assessment showed that the fruit is used to treat gastrointestinal symptoms, and the anthelmintic and constipation treatment claims show potential and need further study. As the fruit has been used as food for a long time, if through research it is found to be effective as an anthelmintic and constipation treatment, the use of it will not only help with mitigating the illnesses but also improve nutrition.

In conclusion, the fruit was found to be a nutritious fruit, which needs further attention in assessing its processing options, marketing and promotion. As there was great variation in the tested properties, there is a need for the screening and selection of appropriate seed sources for the promotion and wide scale planting. It also merits further investigation into its medicinal use.

Sammendrag

Det er mange arter som er lite utnyttet og nesten oversett som kilder til mat i verden i dag. Disse artene står i fare for å forsvinne og kunnskapen om disse for å bli glemt. En slik plante er *Cordia africana*, og selv om denne vokser i hele Afrika og Midtøsten har interessen for dette treet stort sett vært begrenset til bruk som ved. I tillegg til å være et godt brennstoff, har denne studien vist at den har stort potensiale ved å bidra til bedret næringstilgang for befolkningen, spesielt fordi treet er i stand til å produsere frukter selv i tørkeperioder. Frukten er tilgjengelig for de fleste, billig og enkel å bruke og bruksverdien er velkjent for lokalbefolkningen. Med klimaendringer og økende folketall er det viktig at en prøver å ta vare på slike næringskilder og gjøre disse tilgjengelig for større deler av befolkningen ved forbedrede fremstillingsmetoder og markedsføring.

Ernæringsmessig er *Cordia africana* en god kilde til polyfenoler. Den kan også være et viktig bidrag som kilde til vitamin A og jern, som ofte er begrenset i kostholdet i mange afrikanske land, i tillegg til å inneholde vitamin C, kalsium, kalium, magnesium og fosfor. Den inneholder også små mengder zink og natrium. Karakteristikker av treet og fruktene varierte mellom de ulike voksestedene og -forholdene, noe som viser at det fortsatt er potensiale for forbedring av grunnlagsmaterialet, og videre studier er nødvendig for å kunne velge det beste materialet for planteseleksjon.

Prosesseringsmetoder for frisk frukt kan forbedres, og det trengs videre studier på markedsføring og salg. Ved bruk av kabinett-tørke ble tørketiden betydelig redusert; fra 63 til 5 dager. Dette viser at det er forbedringspotensial og bør følges opp med videre studier. Det ble gjort et begrenset forsøk med framstilling av syltetøy. Produktet ble akseptabelt, men det trengs videre studier på selve prosessen, forpakning, holdbarhet og forbrukerstudier. Det trengs ytterligere promotering og markedsføringsarbeid for både frukten og de prosesserte produktene.

Ved litteraturstudier for bruk av frukten i tradisjonell medisin, viste denne at bruken knyttes til behandling av symptomer i magetarmregionen. Bruk av denne frukten for behandling av innvollsorm og ved forstoppelser trengs også videre oppfølging. Siden frukten har lange tradisjoner for bruk som næringsmiddel, og hvis en ved forskning også kan finne positiv effekt ved fordyelsesproblemer som innvollsorm og forstoppelse, kan

denne frukten ikke bare brukes for bedring av disse problemene, men også er et viktig bidrag i kosten.

En kan konkludere med at frukten er næringsrik, men at ytterligere arbeid er nødvendig for å vurdere prosessering, markedsføring og promotering. En fant store variasjoner for en del av komponentene som ble analysert i frukten. Dette må en være oppmerksom på ved videre valg og eventuell oppdyrking for salg av plantematerialet. Det trengs også videre studier for å vurdere fruktens potensial som medisinplante.

List of Papers

Paper I

Tewolde-Berhan, S., Remberg, S. F., Abay, F., Abegaz, K., Narvhus, J. A., & Wicklund, T. (2013). Ferric Reducing Antioxidant Power and Total Phenols in *Cordia africana fruit*. *African Journal of Biochemistry Research* 7(11): 215-224. DOI:10.5897/AJBR2013.0692

Paper II

Tewolde-Berhan, S., Remberg, S. F., Abay, F., Abegaz, K., Narvhus, J. A., & Wicklund, T. (Manuscript-2). *Nutritional Composition of Cordia africana (Lam.) fruit in Different Agroecology and Land Uses* (Submitted to the Journal *Sustainability;* being considered for publication as a special issue proceeding of "The 3rd International Conference on Neglected and Underutilized Species (NUS): For a Food-Secure Africa, Accra, Ghana, 25 to 27 September 2013" – article rejected by *Sustainability* and submitted to *Fruits*)

Paper III

Tewolde-Berhan, S., Remberg, S. F., Abay, F., Abegaz, K., Narvhus, J. A., & Wicklund, T. (Manuscript-3).*Cordia africana (Lam.) fruit processing in the fresh and dried form.* (Submitted to the Journal *Fruits*)

Paper IV

Tewolde-Berhan, S., Remberg, S. F., Abay, F., Abegaz, K., Narvhus, J. A., & Wicklund, T. (Manuscript-4) *Traditional medicinal use of Cordia africana (Lam.) fruit* (Manuscript not submitted)

1. Introduction

We find a lot of lesser known but locally used plants all over the world. These indigenous fruits and plants make substantial contributions to the food security, improved health and nutrition, medicinal treatment, income generation, cultural heritage, and environmental protection both in the drought periods and normal seasons (Akinnifesi et al. 2006; Bharucha & Pretty 2010; Jaenicke & Höschle-Zeledon 2006). On a global review of several studies looking at the importance of wild plants and animals an average of 120 species were found to be used per community. However due to globalization and industrialization, diets are being modernized with less and less emphasis being given to these food sources, which are slowly being replaced by commercialized, cultivated and exotic foods. These plants are not only disappearing from their common landscapes where they grew, but also the knowledge base on their use and processing is also getting forgotten and disappearing with previous generations (Burlingame et al. 2009; FAO 1997; Hawtin 2007; Jaenicke & Höschle-Zeledon 2006; Kahane et al. 2013b; Ross & Loftas 1995; Shepherd 2005; Toledo & Burlingame 2006). Although there are around 30000 known edible plant species in the world, out of which 7000 have been cultivated, just 30 crop plants are used by people to meet 95 percent of the energy needs, while above 60 percent of this is met from only three crops: rice, maize and wheat (FAO 1997; Fowler & Hodgkin 2004; Ross & Loftas 1995). This commercialization and focus on a few crops does not give a proper nutritional replacement to what was a diversified diet (Bharucha & Pretty 2010; FAO 1997; Fowler & Hodgkin 2004). All societies in the world have food production, processing, distribution, preparation and consumption systems adapted to their environments making up the existing food security systems (Gregory et al. 2005). In addition to the slow erosion of these systems as discussed above, climate change and other socio-political problems compound to create food insecurity (Di Falco et al. 2011; Gregory et al. 2005).

The Global Facilitation Unit for Underutilized Species, International Plant Genetic Resources Institute, and International Centre for Underutilised Crops in 2006 defined what underutilised plants are (Jaenicke & Höschle-Zeledon 2006). Within this definition fall several of the crops, semi domesticated plants and wild plants within Ethiopia. These plants are known to make contributions towards food security, improving health and nutrition, medicinal treatment, income generation, cultural heritage, and environmental protection (Jaenicke & Höschle-Zeledon 2006). Despite this fact, the available plant diversity and the corresponding uses these plants are put to, by the local community has been given little attention so far (Bharucha & Pretty 2010; Di Falco et al. 2011; FAO 1997; Fowler & Hodgkin 2004; Jaenicke & Höschle-Zeledon 2006; Kahane et al. 2013a).

1.1 Wild fruits and nutrition

Nutrition is an important part of life affecting people and societies. Nutrition can be defined as "the science of foods and their components (nutrients and other substances), including the relationship to health and disease (actions, interactions and balances); processes within the body (ingestion, digestion, absorption, transport, functions, and disposal of end products); and the social, economic, cultural and psychological implications of eating" (Insel et al. 2010:pp 2). As we can see from the definition the food we eat has implication on our health and ability to overcome diseases, overall body fitness, social, economic, cultural and psychological situation. We take into account all these factors and others when we decide what to eat. It was noted that age, gender, genetic makeup, occupation, lifestyle, family and cultural background as well as availability of food influence our food choice (Insel et al. 2010; Kahane et al. 2013a).

In developing countries, nutrition and food availability are strongly interlinked (Di Falco et al. 2011; Fentahun & Hager 2009; Feyssa et al. 2011; Goenster et al. 2011; Gregory et al. 2005; Kahane et al. 2013a; Lulekal et al. 2011; Müller & Krawinkel 2005; Toledo & Burlingame 2006). Malnutrition is still a dominant factor in the cause of disease and death in the developing world, with basic lack of protein and energy foods and deficiencies in iron, iodine, vitamin A, zinc and folate being the dominant factors (Kennedy et al. 2003; Müller & Krawinkel 2005). The same picture is present in Ethiopia at the current time, with perhaps less mention of zinc and folate deficiency (FAO 2010). The first problem is the basic lack of food thus resulting in lack of protein and energy that the body needs to function. The second is what is known as the hidden hunger, and is manifested in more indirect ways like where the person become stunted in growth, has eye problems, develops thyroid gland related problems, and has weak resistance to diseases. Whether it be in the visible form or the hidden form, malnutrition is affecting the lives of 1.02 billion people, causing 300,000 deaths and is responsible for half of child deaths occurring yearly (Bharucha & Pretty 2010; Kennedy et al. 2003; Müller & Krawinkel 2005) which was 20,000 daily in 2013 (Biesalski 2013). Although this is the fact, international and national efforts to solve these problems have predominantly focused on commercial crops and agriculture based crops, giving little to no attention to neglected crops, semi-domesticated and wild food sources (Bharucha & Pretty 2010; Okigbo 1977; Padulosi et al. 1999; Padulosi et al. 2012).

Several studies at international, regional and national level show that in addition to the formal agricultural species, people both in developed and developing countries are dependent on 120 wild species for food, fibre, fodder, medicines, traps and weapons on average (Bharucha & Pretty 2010). In another review study on the nutritional contribution of wild foods, it was found that wild plants and animals contributed in providing basic nutrition as well as specialized needs of children, pregnant and lactating women. These plants have great potential, and it was noted that during droughts some societies struggle, while under similar conditions others survive with the help of these wild foods (Grivetti & Ogle 2000). In some instances some of these neglected wild foods have been found to have superior nutritional qualities compared to cultivated food crops (Chishakwe 2008; Hawtin 2007; Jaenicke & Höschle-Zeledon 2006; Okigbo 1977; Padulosi et al. 1999; Padulosi & Hoeschle-Zeledon 2004; Padulosi et al. 2011; Padulosi et al. 2012; Schmidt et al. 2010). These wild fruits are also known to have good antioxidant levels (Lamien-Meda et al. 2008). A study of semi-domesticated fruits showed that for the same fruit, fruits grown in the wild had better antioxidant value compared to the cultivated ones (Giovanelli & Buratti 2009). However, the need to identify, document, study and integrate these plants into the formal fields of study was stressed. Their use is greatly hampered due to the fact that scientific information about them is not collected in an integrated and systematic manner. The scientific information on them is also not collected and presented in a form suitable for end users. Therefore, work is needed on their selection for propagation, management and cultivation, processing, marketing and aspects of development into end-user friendly forms. The end users are the individual households and the food industry (Giovanelli & Buratti 2009; Kahane et al. 2013a; Padulosi et al. 1999; Padulosi & Hoeschle-Zeledon 2004; Padulosi et al. 2011; Padulosi et al. 2012; Schmidt et al. 2010).

1.2 Wild fruits as cheap and easily available nutrition

Nutrition is an important fact of life, and malnutrition is an ever growing problem in the wold as it exists (Biesalski 2013; Kennedy et al. 2003; Müller & Krawinkel 2005). Food security is based on food availability, access to food and utilization of food. In the developing world malnutrition happens due to lack of access to food, lack of resources to purchase food and lack of knowledge about alternative food sources (Gregory et al. 2005; Kahane et al. 2013a). This problem is further exacerbated due to the ever increasing human population, existing conflicts, increasing gaps between the rich and the poor and the lack of attention given to indigenous knowledge and its slow erosion (Burlingame et al. 2009; Fentahun & Hager 2009; Flyman & Afolayan 2006; Gregory et al. 2005; National Academy of Sciences 2010; Toledo & Burlingame 2006). The study, use, promotion and conservation of indigenous knowledge and food sources can play a role to solve this problem.

A lot of the indigenous wild food sources are usually more climate resilient as they are better adapted to the local situation, and are able to produce even in adverse climatic situations (Bryan et al. 2009; Di Falco et al. 2011; Feyssa et al. 2011; Gregory et al. 2005; Lulekal et al. 2011; Padulosi et al. 2011; Padulosi et al. 2012). These wild food sources are usually well known by the local community making them cheap, easy to use, and easily accessible. In the majority of cases the production potential, nutritional profile, and use value of these foods is not scientifically known. Where known, recommendations can be made for their use to meet specific malnutrition needs (Flyman & Afolayan 2006). For example in Africa iron, iodine, vitamin A, zinc and folate deficiencies are listed as the top five deficiencies, to meet these needs *Ziziphus spina-christi* can be used to meet iron and zinc needs (Osman & Ahmed 2009), *Zizyphus mauritiana* can be used to meet vitamin A needs (Leakey 1999), and *Conorandus panados* can be used to meet iodine needs (Nkafamiya et al. 2008). With the support of further study, and recommendation for the wider adoption and use of these food sources, local communities can be helped to overcome malnutrition with cheaper and more easily accessible resources.

1.3 Underutilized Species in Ethiopia

Ethiopia has a unique environment with a long culture of crop domestication and plant exploitation which has led to the development of both domestic and wild plants of great diversity (Abebe 2001; Asfaw & Tadesse 2001; Edwards 1989; Edwards 1991; Harlan 1969; Tewolde Berhan Gebre Egziabher 1991). A review work done by Demel Teketay and Abeje Eshete (2004) showed that Ethiopia has 182 species of trees or shrubs in 40 families that have edible fruit or seed. Within the Ethiopian flora there are around 6,000 species, from these 126 species in 53 angiosperm families are known to contain medicinal properties (Poncet et al. 2009). The population in Ethiopia as many other developing countries relies on traditional knowledge for treatment of illnesses, and this has resulted in the accumulation and retention of valuable information on these plants (Abbink 1995; Abebe 2001; Balemie et al. 2004; Birhane et al. 2011; Edwards & Asfaw 1992; Gedif & Hahn 2003; Hailemariam et al. 2009; Hunde et al. 2004; Zenebe et al. 2012). Overall, when analysing the potential of wild and semi-wild food and medicinal plants in Ethiopia it was noted that compared to the high potential the country has, the research done so far is very small (Addis et al. 2005; Asfaw & Tadesse 2001; Birhane et al. 2011; Bryan et al. 2009; FAO 2010; Fentahun & Hager 2009; Lulekal et al. 2011; Poncet et al. 2009; Tadesse 2009). As can be seen from the description above, there is a need to analyse the contributions these plants have in relation to the household with respect to food security, improving health, nutrition, medicinal treatment, income generation, cultural heritage, and environmental protection.

The *Cordia africana* fruit is widely eaten in most parts of Ethiopia and other countries in Africa (Fentahun & Hager 2009; Geteachew Addis et al. 2005; ICRAF 2008; Kebu Balemie & Fassil Kebebew 2006; Mac Lachlan et al. 2001; Tiruneh & Herbert 2008), *C. africana* tree is one of the traditionally used medicinal plants of Ethiopia (Geyid et al. 2005; Yirga 2010). During this study it was found that the fruit is used both fresh and dried, and for both food and medicinal purposes. The tree produces lots of fruit during a season when other food stores are running low and other fruits are produced only through irrigation. The tree is also known to produce fruit in drought years as the tree has deep roots. In an ethno-botanical study done in Ethiopia and other countries in Africa it was found that the fruit of *C. africana* is used as food and medicine (Addis et al. 2005; FAO 2007; Fentahun & Hager 2009; ICRAF 2008; Kebu Balemie & Fassil Kebebew 2006; Mac Lachlan et al. 2001; Obeng 2010; Royal Botanic Gardens 2009; Tiruneh & Herbert 2008). In a study done on the ethno-botanical use of plants *C. africana* fruit was used in northern, central and southern Ethiopia as food and medicinal sources. In addition the paper noted that there was very little study undertaken with respect to looking at the variety of species used as food supplements, especially those of wild and semi-wild plants. In addition, the paper noted that the diversity in the species, the production potential, processing methods and nutritional value of these plants was not well studied (Birhane et al. 2011; Geteachew Addis et al. 2005; Giday et al. 2003; Giday et al. 2007; Giday et al. 2009; Teklay et al. 2013; Teklehaymanot et al. 2007; Zenebe et al. 2012). In a study undertaken by UN-EUE (2001) all over Ethiopia, *C. africana* fell in the category of plants used by children in normal years and where used by adults and other interest groups during years of food shortage and famine. Additionally the study pointed out that there was a strong shortage of information on wild and semi-wild plants, though these formed a major proportion of the diets of most of the food insecure areas of the country (UN-EUE 2001).

1.4 The fruit of *Cordia africana* (Lam.) 1792

Cordia africana (Lam.) is a tree of the family Boraginacea (Legesse Negash 1995; Royal Botanic Gardens 2009), that produces edible fruits. Synonyms for it are *C. abyssinica* R. Br. (Royal Botanic Gardens 2009), *C. abyssinica* R. Br. ex A. Rich.; *C. holstii* Gürke. (ICRAF 2008); *C. ubanghensis* A. Chev.; *C. sebestena*, *Varronia abyssinica*, *Calyptracordia abyssinica* (FAO 2007). Its natural distribution ranges from Saudi Arabia, Yemen, Angola, Ghana, Guinea, Democratic Republic of Congo, Sudan, Eritrea, Ethiopia, Djibouti, Kenya, Tanzania, Uganda, Zimbabwe, Malawi, and Mozambique to South Africa (Figure 1).

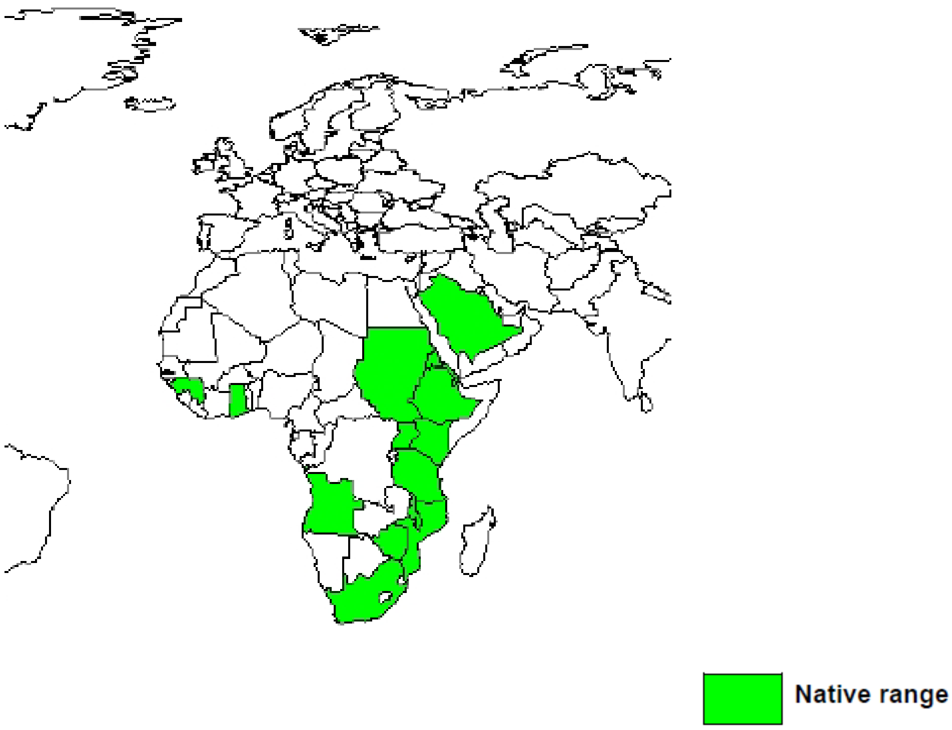

Figure 1. The natural distribution of *Cordia africana*. Source (ICRAF 2008)

Uses: *C. africana* is known to have the following use value.

1. The **tree** (Figure 2) is a good agroforestry species, as it responds well to pollarding, lopping, and coppicing and is widely used as a shade tree in coffee plantations (Derero et al. 2011; FAO 2007; ICRAF 2008; Loha et al. 2009; Obeng 2010; Royal Botanic Gardens 2009).

Figure 2. *Cordia africana* tree in farm fields in fruit (left) and tree in flower (right) - rainy season canopy view.

2. Its **wood** is used for timber, farm equipment, household utensils and fuel (Derero et al. 2011; Emmanuel Neba 2010; FAO 2007; ICRAF 2008; Jansen 1981; Loha et al. 2009; Obeng 2010; Royal Botanic Gardens 2009; Takaoka 2008)
3. The mature **fruits** (Figure 3 and Figure 4) are edible; used to make a sweet drink which can be used as a milk substitute; to make sweets and sweet meats; to make stimulant and alcoholic drinks; and are sold in the local markets in Northern Ethiopia and Sudan (Demel Teketay & Abeje Eshete 2004; El-Tahir 2004; ICRAF 2008; Royal Botanic Gardens 2009).

Figure 3. *Cordia africana* fruits, (left) ripe fruits, (right) ripening fruits eaten by birds

Figure 4. *Cordia africana* fruits, (left) different sized fruits; (right - left to right) fruit with skin and fruit cap, fruit flesh exposed, fruit skin and flesh removed (stone)

4. The **leaves** provide fodder in the dry season (Azene et al. 1993; ICRAF 2008; Jansen 1981; Legesse Negash 1995; Mac Lachlan et al. 2001; Von Breitenbach 1963).
5. The **flowers** (Figure 2 and Figure 5) are very good bee forage, and boost honey production wherever the trees are present (Azene et al. 1993; ICRAF 2008; Legesse Negash 1995; Mac Lachlan et al. 2001; Von Breitenbach 1963).

Figure 5. *Cordia africana*, left leaves and flower buds, right flowers with bee

6. The **bark** is used as a source of tannin in Sudan (El-Tahir 2004).
7. **Traditional medicine**: some literature note that there is traditional medicinal use of the plant (Birhane et al. 2011; Emmanuel Neba 2010; Smith et al. 1996; Takaoka 2008). More specifically migraine, broken bones, wounds, gastritis and constipation were noted to be treated with bark, leaf and fruit (Zenebe et al. 2012). In more detailed studies illnesses and plant-parts used and how they are used are described. The fresh, juicy bark is used to tie a broken bone; this splint is changed occasionally with a fresh one until the bone is healed (ICRAF 2008; Jansen 1981; Kokwaro 2009; Obeng 2010; Royal Botanic Gardens 2009). In Congo the bark is macerated and used to treat madness via nasal application (Chifundera 2001). A decoction made from the bark is used to treat venereal diseases (Kokwaro 2009) and that of the root to treat bilharzia (Jansen 1981). In another study sterile branches are ingested to treat problems of urination at night (Yirga 2010). The wood and root are used as a vermifuges and the ash as skin and mucosae treatment (Royal Botanic Gardens 2009). In Tanzania around lake Victoria region the root is used to treat tuberculosis, cough and asthma (Otieno et al. 2011). The leaves and root are used to treat liver diseases, the root is used to treat amoebiasis, and the root and root bark are used to treat stomach ache and diarrhoea (Giday et al. 2007). For general body ailment inhalation of the boiled leaf vapours is used (Teklehaymanot et al. 2007). The leaves are used ashed and mixed with butter to treat burns and wounds (Jansen 1981; Teklay et al. 2013). The cursed leaf juice is drunk to treat general body ailment, diarrhoea, and tonsillitis and is rubbed into the eye to treat eye infections (Teklay et al. 2013).

The crushed leaf is also applied to wounds for healing (Giday et al. 2009). Old wounds are cured using crushed leaves in Tanzania, and intestinal worms are expelled by eating leaves by Masai and Chagga people in East and South Africa (Jansen 1981).

8. **Lab tested medicinal use:** In a detailed chemical analysis the leaves, stem and bark were found to contain polyphenols, tannins and unsaturated sterol/triterpens. When extracted in water extract at 1000 µg per ml and more inhibited *Neisseria gonorrhoea*, *Streptococcus pyogenous*, and *Stretococcus pneumonia*, while distilled extract inhibited *Neisseria gonorrhoea* at 250 µg per ml and more concentration (Geyid et al. 2005). In another study antifungal properties of the root were tested with brine shrimp lethality, and lethality was achieved at LC_{50} (lethal concentration to 50% of population) 211.4 (117.6-380.1) µg per ml after 24 hour exposure (Moshi et al. 2007).
9. **Industrial uses:** the sticky gum from the fruit of *C. africana* (*Cordia abyssinica)* was studied with details of its chemical composition, sulphuric acid hydrolysis, 2 M trifluoroacetic acid hydrolysis and the extract was shown to have good emulsifying properties (Benhura & Chidewe 2002; Benhura & Chidewe 2004). So far though it does not include *C. africana*, Gum *cordia* as it is being called as isolated from *Cordia rothii*, *Cordia gheraf*, *Cordia oblique* and *Cordia myxa* is being studied as medical tablet constituent and antioxidant carrier and coating on food. As the fruit pulp of the above mentioned *Cordia* and that of *C. africana* shows similar characteristics, this is an important area to explore for the use of *C. africana*. Good results were found with *Cordia rothii* as a tablet binder (Vidyasagar et al. 2011), *Cordia gheraf* as a suspension material for Paracetamol (Doharey 2010), *Cordia oblique* as an agent for sustained drug delivery (Mukherjee et al. 2008), and *Cordia myxa* as an antioxidant carrier (Haq et al. 2013). Finally, the sawdust of *C. africana* was found to be an effective means to clean industrial waste water from lead (PbII) and nickel (NiII) and similar substances (Andrabi 2011).

As can be seen from the review above and several studies within Tigray, *C. africana* is an important tree. In one study it was found to rank first in its multiple use within the study area (Teklay et al. 2013). However, no study has so far looked at the nutritional value of the fruit, its processing potentials, and its medicinal value. Thus this study was proposed to examine the nutritional value of the fruit, its processing potential and traditional medicinal use.

1.5 Fruit processing

The concepts in fruit processing are wide, for example food chemistry, nutrition, processing technology, product properties, sensory analysis, consumer preferences, and marketing studies (Beuchat & Ryu 1997; Claudio 2006; Heldman & Hartel 1997; Lee & Kader 2000; Woodroof 1986). Following only aspects touched upon in this study are discussed. *C. africana* fruit is consumed both fresh and dried. Fresh fruit quality is affected by the fruit genotype, pre-harvest climate, cultural practices, maturity, harvesting methods and postharvest handling (Albert et al. 2011; Alcobendas et al. 2012; Ballester et al. 2011; Bénard et al. 2009; Borochov-Neori et al. 2011; Cordenunsi et al. 2002; Davies et al. 1981; Diamanti et al. 2013; Lee & Kader 2000; Lester et al. 2010; Luthria et al. 2006; Patanè et al. 2011; Trought & Bramley 2011; Worthington 2001). As can be seen from literature, the entire chain from fruit growing to consumption needs to be good so that the fruit quality is also good. In the case of neglected and underutilized foods, this entire chain is usually under developed (Hawtin 2007; Padulosi et al. 1999; Padulosi et al. 2011). For the dominant part these foods are not marketed and are harvested for local consumption, and when marketed they are sold in local markets (Akinnifesi et al. 2006; Feyssa et al. 2011; Hawtin 2007; Padulosi & Hoeschle-Zeledon 2004; Padulosi et al. 2011). To improve marketing of these foods and securing food safety, the production, harvesting, processing, packaging, and market networking needs improvement (Berdegué et al. 2005; Cadilhon et al. 2006; Feyssa et al. 2011; Fischer & Qaim 2011; Huang et al. 2008; Markelova et al. 2009; Shepherd 2005; Teklehaimanot & Haile 2007; Ton 2008).

One of the oldest forms of food processing and preservation methods is drying (Ibrahim 2005; Mac Carthy 1986). Food drying is the process of removal of water from food for the purpose of preservation for extended periods of time, and differs from concentration in that with less moisture the end product is usually solid (Heldman & Hartel 1997). It is a method by which the longevity, safety, convenience and distributability of food is improved. It can also be a very inexpensive and simple process which however needs care as food quality and safety can be influenced by the process (Ekechukwu & Norton 1999; Ibrahim 2005; Mongi et al. 2013; Sharma et al. 2009; Sharma et al. 1995). In the drying process the quality of the end product is affected by the original quality of the food being dried, lipid oxidation and control thereof, Maillard browning reaction and control thereof, nutritional lost and control thereof, microbial load and control thereof, amount of volatile compounds lost and control thereof, protein denaturing and control thereof, and final moisture content (Barbosa-Cánovas & Vega-Mercado 1996; Heldman & Hartel 1997; Mac Carthy 1986; Potter & Hotchkiss 1995). There are several methods of drying food, one of which uses solar energy. The solar drying processes to date can be categorised as open sun drying, direct solar drying and indirect solar drying. In addition to this categorization, the method with which the solar energy is used can also be a distinction criteria in that we have passive (natural convection) and active (forced convection) driers (Sharma et al. 2009). All these methods have their advantages, for example the passive open sun drying method requires minimal technology and investment. Again, the active indirect driers dry the food fast and cause less nutritional loss (Ekechukwu & Norton 1999; Sharma et al. 2009). The overall combination then gives us, open sun drying, direct solar drying the passive way, direct solar drying the active way, indirect solar drying the passive way and indirect solar drying the active way. The selection of the method to be used will depend on resources (financial and technical), scale of the intervention and the value of the final product (Ekechukwu & Norton 1999; Mongi et al. 2013; Sharma et al. 2009; Sharma et al. 1995). The food drying process is known to affect the nutritional value, due to microbial contamination, high temperature, lipid oxidation and Maillard browning processes (Mac Carthy 1986). As some studies indicate, drying results in the loss of vitamin B (thiamine), free and sulphur containing amino-acids, vitamin A (b-carotene), and vitamin C (Eleyinmi et al. 2002; Karabulut et al. 2007; Mac Carthy 1986; Maeda 1985; Oboh & Akindahunsi 2004; Park et al. 2006). On the other hand fibre, mineral and trace element values remained the same, while total phenol and antioxidant values increased (Oboh & Akindahunsi 2004; Park et al. 2006) or decreased (Lim & Murtijaya 2007). Overall, the effect of the loss of nutrition and its significance will be highly dependent on the nutritional requirement of the users.

2. Objectives

The general objective of this study was to evaluate the nutritional value and processing potential of *C. africana*.

The specific objectives were to:

1. Determine the nutritional profile of *C. africana* within the context of the typical Tigrian diet, (Papers I and II)
2. Determine the traditional and modern processing potential of *C. africana*, (Paper III)
3. Investigate special properties that the fruits may have in medicinal, therapeutic and other properties (Paper IV).
4. Develop a new product and evaluate its organoleptic/sensory acceptability by consumers' of the products at laboratory level (Chapter 4.4 in thesis).

3. Materials and Methods

As stated in the overall objective the nutritional value, processing potential and medicinal properties were looked into. In addition, a product namely jam was developed and tested in the laboratory to see its potential acceptability. To design the methodology for this analysis the following points were taken into consideration.

3.1. Nutritional and traditional medicinal use study

The nutritional composition study and the traditional medicinal use survey both covered a wide area and were combined to make the study more economically efficient.

Fruit characteristics and nutritional composition is known to vary according to cultivar (genetic variance, provenance) (Cordenunsi et al. 2002; Davies et al. 1981; Diamanti et al. 2013; Toledo & Burlingame 2006; Wicklund et al. 2005), ripening stage (Al-Maiman & Ahmad 2002; Davies et al. 1981; Vendramini & Trugo 2000), and various environmental conditions such as temperature, rainfall, soil, water availability, exposure to the sun, altitude and ultraviolet radiation (Albert et al. 2011; Ballester et al. 2011; Bhattacharya & Sen-Mandi 2011; Borochov-Neori et al. 2011; Jackson & Lombard 1993; Jogaiah et al. 2012; Trought & Bramley 2011). With semi-domesticated fruits like *C africana* cultivar or genetic material, management and land use related selection criteria applied by local communities (Alcobendas et al. 2012; Khan et al. 2010; Lescourret et al. 2011). In areas where fruit trees are semi-domesticated, trees located near homes and in more easily accessible sites were shown to have some form of selection in contrast to those growing in the wild (Khan et al. 2010). The diversity of *C. africana* has been observed by looking at genetic markers (Derero et al. 2011), seed physical characteristics and germination time (Loha et al. 2006; Loha et al. 2009). These studies found that the populations of *C. africana* investigated had more genetic diversity within rather than between populations. Within Tigray area in Ethiopia, *C. africana* is found to grow in different land use and agroecological conditions. It is an indigenous tree growing in the wild (natural forests, community afforestation sites, and church forests), farm lands, grazing lands and backyards (home gardens) within the altitude range of 500 to 2700 m.a.s.l. (ICRAF 2008; Obeng 2010). The land use classification was used based on closeness to residence and ownership, as closeness was assumed to influence the selection of genetic material as seen for Jackfruit in Bangladesh (Khan et al. 2010).

The agroecology in Ethiopia is classified based on altitude and rainfall (Hurni 1986). This is because day-length is more or less constant and only temperature and rainfall vary. The temperature and rainfall vary on altitude and the direction of the rain carrying clouds, and the rain carrying clouds come from the Atlantic between June and September and from the Pacific between February and April. *C. africana* is found in areas of Tigray categorised as moist highland, at an altitude of 2300 to 3200 m.a.s.l. and rainfall of 900 to 1400 ml per year; dry mid highland with altitude 1500 to 2300 m.a.s.l. and rainfall of less 900 and moist mid highland at the same altitude but with rainfall of 900 to 1400 ml per year; and dry lowland with an altitude less than 1500 m.a.s.l. and rainfall less than 900 ml per year. Thus there were four agroecologies.

Typically in the Tigrayan context the fresh fruits are collected and eaten in the home in the evenings while waiting for dinner or after dinner while socializing. The fresh fruits are also collected and sold in the markets. The fruit is also dried on the tree, and just before the rainy season starts the dried fruits are collected and stored in clay jars (pots), skin sacks, or straw based containers. These dried fruits are then used when needed for socializing, medicinal purposes or nutritional supplementation. On average people will eat about 100 grams of the fresh fruit at any given time, unless they are using it for treating gastro-intestinal illnesses, for which they would consume about 750 grams at one time.

The fruit sampling tried to take into account the different land use and agroecological zones. The existing study areas where *C. africana* was found and used were divided into four agroecological zones and three land use systems within the four agroecological zones. For the selection of the specific study sites, a woreda (second smallest level of administration in Ethiopia) was randomly selected from each of the agroecological zone so as to represent the agroecological area. Estimated rainfall data were added to this in order to determine the selection of the four woredas. However, no adequate number of trees could be found in the three land use categories in Irob and Atsbi Womberta woredas. As a result, two other woredas were selected as substitutes. Within the selected woredas, a village was purposely selected where *C. africana* could be found growing in the wild, farm lands and backyards in consultation with the woreda level forestry experts. Ten trees were randomly selected from each site of the wild, farm (grazing land) and backyards. From each tree, 250 to 450 g mature fruits were collected, labelled, and placed in a cooler which had an average temperature of +4^{o}C, during transport to the Mekelle University lab. The evaluation of the ripening of the fruits was based on colour but also firmness and splitting of the skin due to precipitation. Local boys were employed to select the best fruit bunches to bring down, as they knew the trees and the fruits best. The transport from Laelay Maychew and Raya Azebo woredas took 24 hours from collection to arrival of the fruits to the lab, and that of Alaje and Hintalo Wajerat arrived 5 hours after collection.

Nutritional analysis

The collected fruits were then taken to the lab, and their physical characteristics of size, colour, firmness and weight and their chemical characteristics of ash, total protein, moisture content, total soluble solids, pH, total acidity, vitamin A, vitamin C, Fe, Cu, Mg, Zn, Ca, Na, K, total phenol (Folin Ciocalteu`s reagent) and Ferric Reducing Activity Power (FRAP) were measured. The results of these were summarised and analysed using statistical software. The lab techniques used are summarised in Table 1.

Table 1. A summary of the techniques used for fruit measurement

No.	**Physical description of the fruits**
1	Size: (cm) using a micro-calliper (Bertin et al. 2009).
2	Colour: (L*a*b*) Natural Colour Systems (Hård & Sivik 1981).converted to (CIE) L*a*b* scale (Osorio & Vorobyev 1996; Özkan et al. 2003)
3	Firmness: personal Medium, Soft, and Firm
4	Weight: (g)digital balance sensitivity 0.001g (Ercisli & Orhan 2007)
	Nutritional composition
5	Ferric Reducing Activity Power (FRAP): (mg/100g Trolox equivalent) following Konelab 30i outline (Volden et al. 2008; Zargar et al. 2011).
6	Total Phenols (TP): (mg/100g Gallic acid equivalent) following Konelab 30i outline using Folin Ciocalteu`s reagent (Volden et al. 2008; Zargar et al. 2011).
7	Ash: (%) ashing of the whole fruit and separated stone was done using the AOAC 940.26 standard (Horwitz & Latimer 2005).
8	Total protein: (%) following AOAC 2001.11 (Horwitz & Latimer 2005)
9	Moisture content: (%) following AOAC 934.06 standard (Horwitz & Latimer 2005)
10	Total soluble solids: (% Brix) AOAC 932.12 standard (Horwitz & Latimer 2005)
11	pH: (pH scale) portable automatic pH meter
12	Total acidity: (% citric acid equivalent) following AOAC 920.92 standard (Cardwell et al. 1991; Horwitz & Latimer 2005)
13	Vitamin C: (mg/100g) following AOAC 967.21 standard with the Metaphosphoric acid–acetic acid solution replaced by 0.1% oxalic acid (Eleyinmi et al. 2002).
14	Vitamin A: (μg/100g) the trans-β-carotene was measured using reversed phase – high performance liquid chromatography. Reference method: DIN EN 12823-2:2000 (Bernhardt & Schlich 2006; Blake 2007; Szpylka & W. Devries 2005).
15	Mineral and trace elements: (mg or μg/g) were measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Kira et al. 2004).

Medicinal use survey

Alongside the fruit sample collection a survey was undertaken to assess the traditional medicinal use of the fruit. In the four selected woredas 10 key informants were identified and interviewed. Where possible a group of an additional five key informants were interviewed. As it was not always possible to get five people together, the group interviews were done with two and three people where applicable. The key informant selection was again done in consultation with the woreda level forestry experts. These key informants were then interviewed (Figure 6), and the information was collected in a semi structured interview questionnaire presented in Table 2. The results of the survey were then summarized into frequency tables using statistical software.

Table 2. Semi-structured questionnaire used for the study

A. Basic information about key informant
Interviewer:
Date of interview:
Name of interviewee:
Interview number:
Woreda:
Tabia:
Kushet:
Zone:
Specific site:
Number of years in the tabia:
Distance to woreda market (in minutes.):
Distance to the nearest market (in minutes):
Distance to a transport service (in minutes):

B. Questions

Do you use or know how to use *Cordia africana* to treat illness or complaints?

If yes fill out the following table:

Treated illness	Symptoms of the illness	If combined with other plants	Part of the plant used	Method of plant preparation	Method of administration	Frequency of use for one occurrence

Is *C. africana* used alone or in combination with other plants, if other plants are combined just mention their names

Figure 6. Group key informant interview.

3.2. Traditional and conventional fruit processing potential

During the study it was found that the fruit is used both in the fresh and dried form. The tree produces lots of fruit during a season in which other fruits are produced only through irrigation and other food stores are running low. The tree is also known to produce fruit in drought years as it has deep roots. The fresh fruit is collected, sorted and cleaned by hand and laid out in plastic pots in the sun before and during selling. This marketing of the fresh fruit is limited to small scale local markets. However the dried fruit is mainly consumed at household levels and seldom sold. The improvement of marketing this fruit is important in that it improves the overall nutrition of the Ethiopian population while also improving the income of local producers and processors. For the improvement of marketing the fruit and the securing of food safety the processing, packaging, and market networking needs improvement (Berdegué et al. 2005; Cadilhon et al. 2006; Feyssa et al. 2011; Fischer & Qaim 2011; Huang et al. 2008; Markelova et al. 2009; Shepherd 2005; Teklehaimanot & Haile 2007; Ton 2008). To look at the post-harvest processing improvement potential, processing methods that included collection, sorting, washing, air drying under shade, and storage in cleaner open air containers was compared to the traditional processing methods. In addition to the fresh fruit processing, the dry fruit processing methods were also looked into. Fruit drying is an age old method of preservation, with unique traditions and methods all over the world (Ibrahim 2005). Traditionally, the fruits are dried on the tree like dates (Barreveld 1993; Falade & Abbo 2007). The process of drying fruits on trees has not been studied in detail except for that done on dates. Thus the investigation of the actual drying process was found to be important. In addition, it was thought that it may be more nutritious and economical to dry the fruits in solar driers. Thus a comparison of the two processes was undertaken. Five *C. africana* trees were selected and marked. All the processing tests were undertaken on fruits form these trees.

Fresh fruits: Fruits were collected from all five trees, and these were divided into three parts. The first part was frozen immediately. The second part was washed; air dried, and laid out in the shade for seven days to represent what would happen to it if it was sold in shops. After seven days they were frozen. The third part was given to a traditional fruit merchant to process. She washed the fruits; air dried them and laid them out in plastic containers on the floor in the market. The fruits were thus exposed to the sun, wind, dust

(Figure 11) and handling during the day and were taken into the house overnight for seven days. After seven days they were frozen. All the fresh fruits processed and not processed were frozen at -20^{o}Cuntil processed for further analysis.

Dried fruits: From each tree, ten bunches were selected. From these ten bunches, five were taken to the direct solar drier and five were left on the trees. On each of the ten bunches ten fruits were marked out with thread (Figure 7 and Figure 8). On the tree, the fruits were covered with a mesh cloth to protect them from bird attack. In the direct solar drier, each fruit was measured daily, on the tree each fruit was measured every other day. The fruits vertical and diagonal diameters, firmness and colour were measured. Each time a measurement was taken; two fruits were taken out to determine the moisture content of the bunch. The drying process was done in 2010 and 2012, while marked fruit measurement was done only in 2010.

Figure 7. On tree drying process with mesh cloth cover and different coloured threads to mark singular fruits for follow-up.

Figure 8. Box or cabinet direct solar drier and singular different coloured thread marked fruits in the drying process.

In the field as well as the lab, during the drying process and storage tests the physical characteristics of size, colour, and firmness and the chemical characteristics of moisture content, Ferric Reducing Activity Power (FRAP), total phenol (Folin Ciocalteu`s reagent), vitamin A, vitamin C, basic sugars and organic acids and volatile organic compounds were measured. The results of these were summarised and analysed using statistical software. The lab techniques used are summarised in Table 3.

Table 3. A summary of the techniques used for fruit measurement

No.	Physical description of the fruits
1	Size: (cm) using a micro-calliper (Bertin et al. 2009).
2	Colour: (L*a*b*) Natural Colour Systems (Hård & Sivik 1981).converted to (CIE) L*a*b* scale (Osorio & Vorobyev 1996; Özkan et al. 2003)
3	Firmness: personal Medium, Soft, and Firm
	Nutritional composition
4	Moisture content (%): was determined following the AOAC 934.06 standard (Horwitz & Latimer 2005).
5	Ferric Reducing Activity Power (FRAP): (mg/100g Trolox equivalent) following Konelab 30i outline (Volden et al. 2008; Zargar et al. 2011).
6	Total Phenols (TP): (mg/100g Gallic acid equivalent) following Konelab 30i outline using Folin Ciocalteu`s reagent (Volden et al. 2008; Zargar et al. 2011).
7	Vitamin C: (mg/100g) following AOAC 967.21 standard with the Metaphosphoric acid–acetic acid solution replaced by 0.1% oxalic acid (Eleyinmi et al. 2002).
8	Vitamin A: (µg/100g) the trans-β-carotene was measured using reversed phase – high performance liquid chromatography (rp-HPLC). Referanse method: EN 12823-2:2000 (Bernhardt & Schlich 2006; Blake 2007; Szpylka & W. Devries 2005).
9	Basic sugars and organic acids: (ppm) a method using High Pressure Liquid Chromatography (HPLC) was used (Kelebek et al. 2009; Narvhus et al. 1998).
10	Volatile organic compounds: (ppm) a method using Headspace Gas Chromatography (HSGC) was used (Narvhus et al. 1998).
11	Volatile organic compounds: where substance concentration was not measured, a method using Headspace Gas Chromatography Mass Spectrometry (HSGCMS) was used (Volden et al. 2011).

3.3. The New Product, *Cordia africana* Jam

Fruits were collected from the trees in Mekelle University campus, and several attempts were undertaken to develop a product that would have acceptable organoleptic properties. A spiced paste was tried, but the sweet taste from the fruits gave a mixture of tastes that is not common in the Ethiopian cuisine. It was then thought that the sweet taste would mellow through fermentation, thus the mix was allowed to ferment spontaneously. After seven days of fermentation, though the sweet taste mellowed, the fruity sensation was still present. Although some possibilities for further exploration could be seen, it was thought perhaps another product that was also being investigated namely the jam had better prospects.

Initially the jam was tried after separating and homogenising the flesh and fruit, however the water used in this process left the final product watery. Another method of cooking the whole fruit and then separating the flesh and skin by sieving was found to be a better alternative. The jam produced in this manner was then tested for preliminary acceptability by food science students at the University. The results of this are summarised and presented in Table 6.

4. Results and Discussion

4.1. Nutritional composition of *Cordia africana* fruit

The main result of the nutritional composition study was that the fruit of *C africana* had high variation with respect to its physical characteristics. This variation was significant across the different land use and was not across the different agroecologies. This could be the effect of both selection and micro-environmental conditions. The sizes and weight of the fruits progressively declined from backyard to farmland to wild land uses. This has implications for the further development of the fruit, as it means that care needs to be taken during selection of the propagation material and environmental conditions of the planting site.

When we look at the chemical composition of the fruits, we also find high variation of the values themselves. The variation of this occurs more across agroecology than across land use, though total phenol, calcium, vitamin A, and total acidity varied across the land use more than they did across agroecology. Because the variables being considered are many and each varied in a different order, no clear picture could be drawn with respect to implication for use. The variation of vitamin A across land use as can be seen in Figure 9, shows higher β-carotene levels for the backyard fruits as compared to the farmland and wild fruits. This variation was shown to be significant in the nested ANOVA, yet the Tukey's grouping showed no difference. The higher values in the backyard can again be due to fruit quality selection or micro-climatic conditions. The variation of iron content across acroecology is presented in Figure 10. As can be seen the highest content of iron was recorded for the fruits collected in the lowlands, while the lowest content of iron was that of the highlands. This can probably be explained by the fact that the geology and soil of these sites was different, thus providing different nutritional conditions for the trees growing there. Such effects have been noted in other studies (Havlin et al. 2009; Lucas et al. 1942).

Nutritionally, the fruit was found to be a very good source of total phenols. It is also a good partial source for the nutritionally important vitamin A and Iron, as well as for protein, vitamin C, calcium, copper, potassium, magnesium, manganese, and phosphorus. It was found to contain very little zinc and sodium. In light of malnutrition in the form of basic lack of protein and energy as well as lack of iron and vitamin A that is found in Ethiopia and many African countries, the promotion of this fruit as a source of nourishment could help in the malnutrition mitigation efforts.

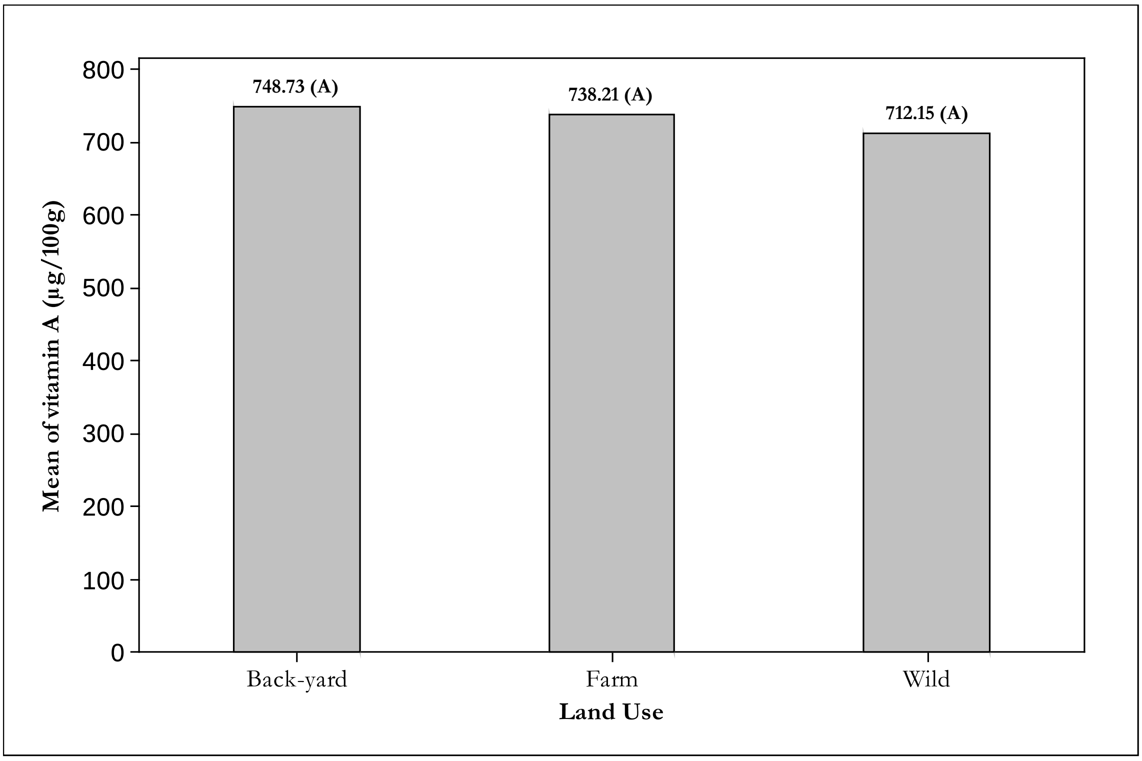

Figure 9. Tukey's ranking and grouping of mean values of β-carotene contents of *Cordia africana* fruit across land use

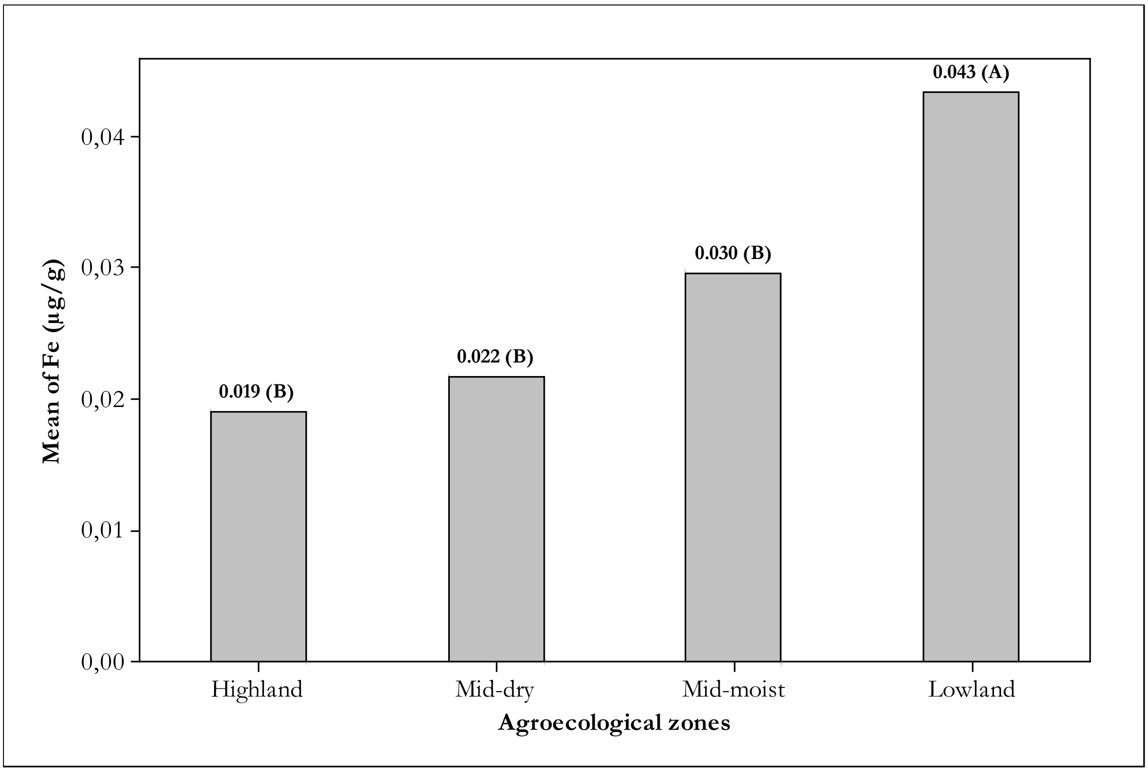

Figure 10. Tukey's ranking and grouping of mean values of iron contents of *Cordia africana* fruit across agroecology

4.2. Traditional Medicinal Properties

During the survey it was found out of the four woredas studied, only three used the tree for medicinal purposes. Though the survey focused on the use of the fruit, the use of the leaves was also repeatedly mentioned by the key informants. It was found that the fruit was mainly used to treat gastrointestinal symptoms, although other treated symptoms like skin related illnesses, jaundice and sore throat were mentioned these were mentioned in relation to the use of leaves. The leaves have already been shown to have anti-bacterial and anti-fungal properties and may be able to help with these symptoms depending on the illnesses causing the symptoms. With respect to the use of the fruit, the gastrointestinal symptoms mentioned were diarrhoea, abdominal pain, mouth-watering, bloating, nausea, weakness related to malnourishment, worms in stools, abdominal pain caused with eating, loss of appetite and constipation. From among these, worms in stools are a clear indication of the fruit's use as an anthelmintic substance. *Cordia dichotoma* (Maisale et al. 2010) fruit was found to have anthelmintic properties and this may be a very good indication for further study. In addition it is known that high fibre content in foods consumed do help with constipation, as the fruit is consumed whole and the fruit stone is not digested and it may act as a bulking to reduce constipation. Therefore, one can see that there is possible potential for further exploration of the uses the local people have identified.

4.3. Traditional and conventional fruit processing potential

The comparison of the traditional and conventional fruit processing methods showed that the traditional method of processing and selling fresh fruits resulted with fruits that were significantly drier and having 7.6 grams of dust per kilo of fresh fruit (Figure 11). This showed the need for placing them in the shade away from dust and direct sunlight. The fruit drying process in the cabinet direct solar drier shortened the drying process from 63 to 5 days; however the taste of the fruits needed time to mature to be of similar quality (Figure 7, Figure 8, and Figure 12). The nutritional composition study showed that the fruit was a good source of total phenols. It was also a good partial source for the nutritionally important vitamin A and iron, as well as for protein, vitamin C, calcium, copper, potassium, magnesium, manganese, and phosphorus. As the drying process was expected to only affect vitamin A, vitamin C and total phenol content (Bosscher et al. 2003; Mac Carthy 1986; Oboh & Akindahunsi 2004; Ünal et al. 2005), while increasing the amount of mineral and trace elements due to concentration (Bosscher et al. 2003; Park et al. 2006; Ünal et al. 2005), only moister content vitamin A, vitamin C and total phenol contents of the processed fruits was measured. Drying is also known to affect some amino acid compounds reducing the protein levels (Mac Carthy 1986; Maeda 1985), and the effect of concentration increasing crude protein levels is also possible(Maeda 1985). However crude protein contents of the dried fruits were not measured in this study. The total phenol and vitamin A and vitamin C contents of the dried fruits were found to still be good in that consumption of 200 grams of the fruit was enough to meet daily requirements for total phenols. One kilo of fruit would be needed to meet vitamin A and vitamin C daily requirements, thus the dried fruits can contribute to the partial fulfilment of vitamin A and vitamin C daily requirements. As the taste of the fruit dried in the cabinet drier was different from that of the fruit dried on trees, basic sugar, organic acid and volatile organic compounds were also compared. This comparison was however offset by the fact that the years in which the drying was undertaken being exceptionally wet and dry years. The drying process showed great potential as a fruit processing option.

During the study the sale of dried fruits was not observed. The use of this fruit in this form needs promotion, as the fruit can be made available off season.

Figure 11. Dust collected from fresh fruits that were processed in the traditional way of selling them in the market.

Figure 12. Dried *Cordia africana* fruits

4.4. Organoleptic evaluation of *Cordia africana* jam samples

C. africana fruits are nutritious and eaten in Tigray, Ethiopia and other parts of Africa (FAO 2007; ICRAF 2008; Obeng 2010; Royal Botanic Gardens 2009). As a tree fruit, these fruits are available in the dry season when production of other fruits is low. The fruits are produced even in drought years, as the tree has deep roots. The fruit is also available off season in the dried form. The dried fruit is nutritionally good as shown in the fruit processing study. However, the dried fruit is time consuming to eat. Therefore, other avenues of processing the fruit and making it available off season were deemed necessary to explore. Jams are good methods of processing and preserving the fruits. Jam processing can also easily be done at a cottage industry level making it an easy technology to adopt for the women cooperatives set up by the project under which this study was done.

Objective

Development of a new product (Jam), and organoleptic/sensory evaluation on consumers' acceptability of the product at laboratory level.

Methodology

Fruits were collected from trees on Mekelle University campus. The collected fruit samples were cleaned and checked for damage. The cleaned fruits were then taken for further processing.

Several attempts were undertaken to develop a product that would have acceptable organoleptic properties. A spiced paste was tried, but the sweet taste from the fruits gave a mix a taste that is not common in the Ethiopian cuisine. Even after fermentation, the organoleptic properties still needed improvement. As another product also being developed namely the jam, showed better prospects this idea was abandoned. Thus focus was given to the jam.

1st attempt: initially it was considered better to separate the flesh and fruit before cooking. For this, 1023 grams of fruit was taken, the fruit cap was removed; and then the fruit skin was removed. Following this, the sticky flesh was dissolved into 1200 ml water and by blending it with an egg whisk. When the stone and flesh were separated, the stones were taken out. Following this, the skin was placed back into the dissolved fruit flesh and blended into a homogenized fruit pulp paste. Unfortunately, after cooking the water used for the fruit pulp separation caused a watery consistency, resembling a juice rather than a jam.

2nd attempt: The cleaned *C. africana* fruits were cooked whole and then passed through a sieve to separate the flesh from the stone. Next pectin from lime (*Citrus aurantifolia*) was added to improve the consistency. This gave a jam of acceptable consistency. The recipe is presented below. The jam was then divided into two and sugar was added to one sample. This gave two jams; one with and one without sugar. Both sets of jam were then used for organoleptic tests by students.

Recipe of C. africana jam:

1. 1402 grams of fruit were washed and placed in to a pressure cooker (Figure 13)
2. 780 ml water was added
3. The pressure cooker was closed and the fruits were cooked at medium heat. They were cooked for 7 minutes after pressure had built up and hissing started. The overall time was 17 minutes.
4. The mix was sieved in a 2 mm x 2 mm sieve to separate the stone and the flesh, the separated flesh weighed 893 grams and the stones weighed 1251 grams (Figure 13).
5. The mix was homogenised in a blender (Moulinex click and mix one speed for 73 seconds)
6. Through this process, 875 grams of jam was produced. A 63 gram sample was taken at this step for the sugar free jam test.
7. Three table spoons (12 grams) of sugar were added into the remaining 800 grams of jam.
8. Into both samples lime pectin (quarter of a tea spoon in the 63 grams and 3 and a quarter tea spoon in the 800 gram) was added, and both samples were then heated on the stove for 3 minutes at medium heat and poured into jars while hot. The Jars were sealed and tasting took place the next day.

9. The dry matter percent of the sugar free sample was 31.9% and that with sugar added was 32.3%.

Figure 13. Pictures of jam preparation: top left to bottom right, cooked fruits in pressure cooker, the sieve used, fruits prepared for sieving, fruits being sieved, stones left after sieving, and the blended jam.

Organoleptic test: open sensory evaluation is not a common practice in Ethiopia, and eating in public is considered to be culturally offensive. As the major consumer of jams in Mekelle city are university students, it was assumed that they will be a good sample to test the product on. Twenty six students aged 19 to 21 and twenty nine students aged 29 to 40, all of whom were food science students were used for the evaluation. These students had been taking classes in sensory evaluation and the different methods used. In addition before the evaluation they were given instruction on how the evaluation worked and how the score cards were to be filled out. As there were two jams, one with sugar and another without there was no need for randomization. The one with sugar was labelled A and the one without sugar was B. Uniform flat bread was baked and prepared. Each piece of bread was cut into slices of 4 cm x 4 cm. The bread was placed on a tray and the labelled jam was placed on either side of the tray. The students were left to apply as much jam as they wanted to undertake the test, they were however instructed to apply equal amount of the jam in both instances. The score cards were explained and given to the students (Table 4 and Table 5). The students then did their evaluation. The score cards were then collected, and the summarised scores are presented in Table 6. The jam was also tested for vitamin A content, and it was found to contain 354 µg per 100 grams, which is 48% of the fresh fruit content. Though not high, it is still a substantial amount, as preserved it becomes especially available in seasons of shortage. Consumption of 846 grams will meet the daily requirement of Vitamin A, therefore it can be used as a partial source. The iron content is not expected to decrease due to processing and similar levels of iron are expected in the fresh, dried, and cooked fruits. In other studies cooking increased availability of micronutrient by reducing anti-nutritive aspects (Bosscher et al. 2003; Kumari et al. 2004; Messina & Reed Mangels 2001; Viadel et al. 2006; Ünal et al. 2005). The vitamin C content is expected to decrease by cooking for 24 minutes, and thus the amount was not measured (Kumari et al. 2004).

Table 4. Criteria based score card

Name of evaluator: ________________________Age__________Sex__________

Jam colour:	3. Golden brown	2. Brown	1. Dull brown
Smell:	3. Fruity	2. Sugary	1. Other (describe)
Taste:	3. Fruity	2. Sweet and sour	1. Bitter
Mouth feel:	3. Smooth	2. Lumpy	1. Rough
Consistency:	3. Firm	2. Lose	1. Watery

Sample code	Jam quality descriptors				
	Jam colour	Smell	Taste	Mouth feel	Consistency
A					
B					

Comment:

The criteria based scores had a highest mark of 3 and a lowest of 1.

Table 5. Hedonic score card on jam characteristics

<table>
<tr><td colspan="6">Name of evaluator: ________________________Age__________Sex__________
Please state if you find the Jam colour, smell, taste, mouth feel and consistency
9, Extremely desirable 4, Slightly undesirable
8, Very desirable 3, Undesirable
7, Desirable 2, Very undesirable
6, Moderately desirable 1, Extremely undesirable
5, Slightly desirable</td></tr>
<tr><td rowspan="2">Sample code</td><td colspan="5">Jam quality descriptors</td></tr>
<tr><td>Jam colour</td><td>Smell</td><td>Taste</td><td>Mouth feel</td><td>Consistency</td></tr>
<tr><td>A</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Comment:</td></tr>
</table>

The hedonic based scores had a highest mark of 9 and a lowest of

Results

The results of the sensory evaluation are presented in Table 6.

Table 6. Summary of the score card values

Hedonic score card on jam characteristics, mean (min-max)			Criteria based, mean (min-max)		
Jam	A (no sugar)	B (with sugar)	Jam	A	B
Jam Colour	6.90 (1-9)	7.24 (1-9)	Colour	2.31 (1-3)	2.19 (1-3)
Smell	7.34 (3-9)	7.55 (3-9)	Smell	2.08 (1-3)	2.00 (1-3)
Taste	7.31 (5-9)	7.45 (3-9)	Taste	2.23 (2-3)	2.23 (1-3)
Mouth feel	5.97 (1-9)	6.55 (1-9)	Mouth feel	1.62 (1-3)	2.19 (1-3)
Consistency	6.36 (3-9)	6.68 (2-9)	Consistency	1.77 (1-3)	2.46 (2-3)
Average	6.77	7.09		2.00	2.22

As can be seen from Table 6, both jams had above average scores, but the jam with sugar in it was preferred. In conclusion, preparation of the jam is a good alternative of preserving the fruit and making it available to meet partial iron and partial vitamin A needs of the people. The sensory panellists were asked if they would buy the product if made available in the market, their response was yes provided it was cheaper than the existing jams on the market. Further studies are needed to test aspects like packaging, shelf life, pricing and economic feasibility. This study was an indication of a possible product.

5. Identified gaps for future study

The overall study indicated that *C. africana* is a useful tree with a nutritionally useful fruit that has potential for processing and marketing. In light of the climate change mitigation efforts all over Africa, and the afforestation efforts within Ethiopia, the multipurpose function of this tree merits attention. For the realisation of the full potential of this fruit there is work needed in the following areas.

1. Studies on the large scale processing, packaging, and marketing possibilities including shelf life, handling and market network structures.
2. Awareness creation and promotion of the nutritional potential of the fruit.
3. Screening of fruit quality and identification of good quality seed sources for promotion in planting at both communal and individual levels.
4. Further research into the medicinal properties.

Overall with the wide campaign of environmental rehabilitation work taking place within Ethiopia and climate change adaptation works within Africa, the use and promotion of this fruit and similar fruits can play an important role and need due attention.

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7. Papers I to IV

PAPER I

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Full Length Research Paper

Ferric reducing antioxidant power and total phenols in *Cordia africana* fruit

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Antioxidants are beneficial compounds found in a lot of foods. *Cordia africana* (Lam.) is a small fruit eaten all over Tigray and other parts of Ethiopia. The fruit was tested for its antioxidant content using the ferric reducing antioxidant power (FRAP) assay and total phenols (TP) measured with Folin Ciocalteu`s reagent, across four different agroecological zones and three land use classes in Tigray. The average FRAP value on dry weight basis was 30.8 ± 1.45 mg Trolox equivalent 100 g^{-1} fruit, and the average TP value on dry weight basis 2317.0 ± 104.0 mg gallic acid equivalent 100 g^{-1} fruit. Both FRAP and TP values were found to be significantly ($p < 0.05$) different across the agroecology with the lower altitude agroecology giving the highest value and the dry mid altitude agroecology giving the least value. The difference in land use showed no effect on the FRAP value; however the TP values were significantly ($p < 0.01$) different across the different land use. The highest value of TP was found in the wild and the lowest was found in the backyard land uses. *C. africana* is a fruit with good quantities of TP, and small amounts of antioxidants measured with FRAP. Both FRAP and TP values showed variation across agroecology, while only the TP content vary across land use. The fruit was also found to have 9.07 mg 100 g^{-1} fruit vitamin C, which makes it a good source of the vitamin to meet part of the daily requirement. As antioxidants and vitamin C are highly beneficial to general health, the consumption of this fruit should thus be recommended and promoted.

Key words: *Cordia africana* fruit, ferric reducing antioxidant power, total phenol, agroecology, land use.

INTRODUCTION

The benefits of antioxidants have been studied and discussed by many scientists in food science, medical science and general health areas (Baumann, 2009; Cadenas and Packer, 2002; Packer et al., 2000; Sen et al., 2000; Tardif and Bourassa, 2006). These show the multi-disciplinary nature of the studies and the multiple use and application of antioxidants. When it comes to *Cordia,* several species have been investigated for their antioxidant properties of the fruits, roots, barks and leaves. For example the leaves of *Cordia wallichii* and

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Abbreviations: ANOVA, Analysis of variance; **FRAP,** ferric reducing antioxidant power; **TP,** total phenol measured with Folin Ciocalteu`s reagent; **m.a.s.l.,** meters above sea level; **DW,** dry weight basis; **TE,** trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent; **GAE,** gallic acid equivalent.

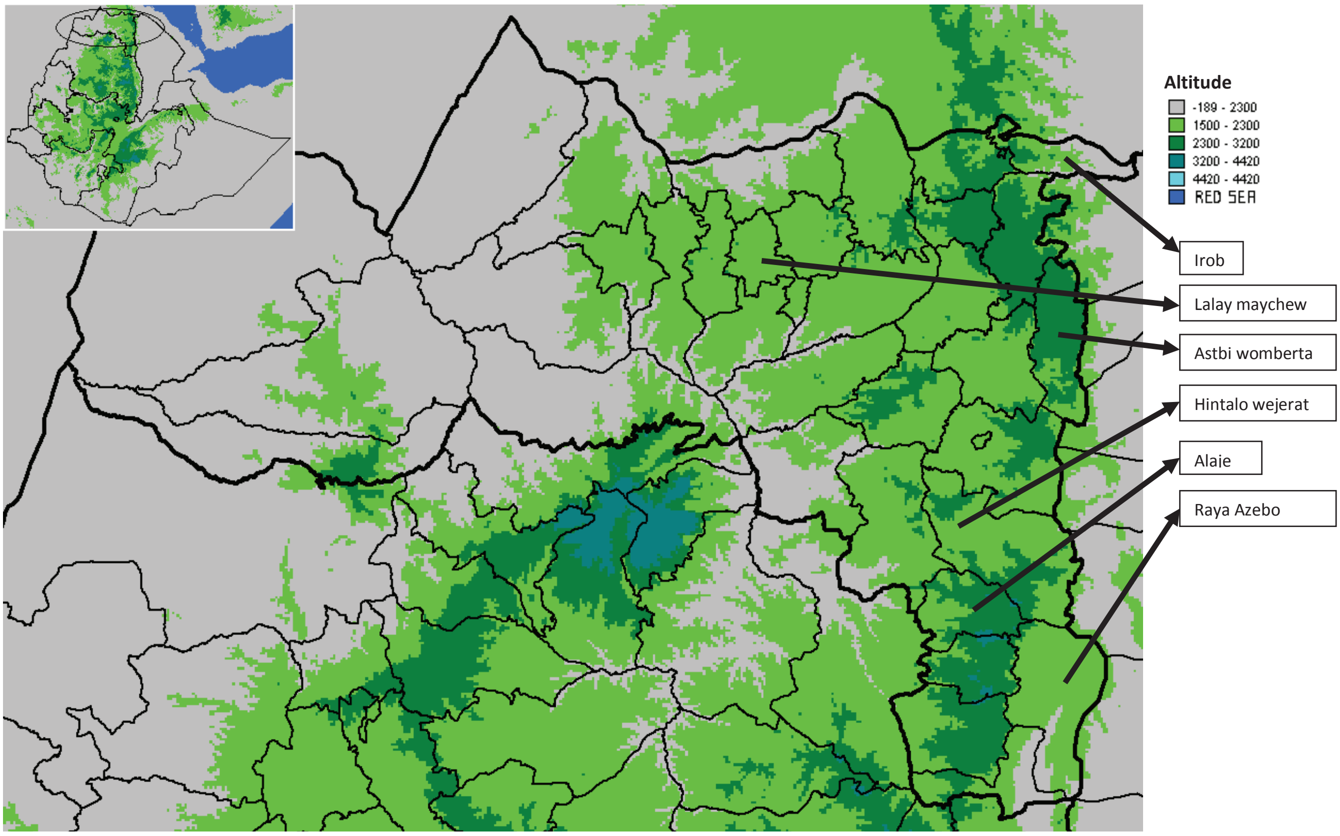

Figure 1. Map of selected woredas in Tigray, Ethiopia, East Africa, showing their relative location and altitude (Generated on DIVA-GIS software). Altitude: Irob; Lalay maychew; Astbi womberta; Hintalo wejerat; Raya Azebo; Alaje.

Cordia verbenacea were looked into by two different studies (Makari et al., 2008; Michielin et al., 2011).

The antioxidant content of fruits vary due to cultivar (genetic variance, provenance) (Cordenunsi et al., 2002; Howard et al., 2003; Kotíková et al., 2011; Wicklund et al., 2005), ripening stages (Gull et al., 2012; Kotíková et al., 2011; Vendramini and Trugo, 2000), various climate conditions such as season and production location (Howard et al., 2003; Iqbal and Bhanger, 2006), temperature (Howard et al., 2003; Wang and Zheng, 2001), altitude and ultraviolet radiation (Bhattacharya and Sen-Mandi, 2011) in addition to overall environmental conditions (Oh et al., 2009; Wang, 2006; Yuri et al., 2009).

Cordia africana is a fruit found wide spread in the Middle East, West, East, and Southern Africa. It is known by the name Sudan teak, East African Cordia, large-leafed Cordia, and Sebastian fruit (ICRAF, 2008). In Tigray, *C. africana* fruit is eaten by the local community during its fruiting season of April to June. It is collected and eaten by shepherds and children when found in the wild, and collected, and eaten or sold by women and children when grown in farms or backyards. Generally, the fruit is eaten fresh, however traditionally the fruit is also dried and kept for use during off season. The objective of this study was to determine the antioxidant levels of *C. africana* within the context of the typical Tigrian diet when consumed fresh.

MATERIALS AND METHODS

C. africana fruit sampling strategy

In Tigray, it is found that *C. africana* grows in the wild (natural forests, community afforestation sites, church forests), farm lands, grazing lands and people's backyards (home gardens) within the altitude range of 1500 to 2950 m.a.s.l. Thus, the present experimental design took into account the different agroecological and land use patterns. In two studies, the diversity of *C. africana* was observed by looking at genetic markers (Derero et al., 2011), seed physical characteristics and germination time (Loha et al., 2006; Loha et al., 2009). The results of these studies found that the populations of *C. africana* investigated had more genetic diversity within the populations rather than between populations. Thus, the present experimental design took into account both inter- and intra-population diversities, looking at variations across the different populations at the different agroecology and land uses.

The existing study areas where *C. africana* grows were divided into four agroecological zones. A woreda (second smallest level administrative body in Ethiopia) was randomly selected from each of the agroecological zone so as to represent the agroecological area. Figure 1 shows an altitudinal map of Tigray Regional State showing the three different agroecological zones based on altitude. Estimated rainfall data were added to this map in order to determine the selection of the four woredas. The four randomly selected woredas were: Irob (Weyna dega, midland) which is mid altitude 1500-2300 m.a.s.l., moist with mean annual rainfall ranging from 316 to 823 ml year^{-1}; Laelay Maychew (Weyna dega) mid altitude 1500-2300 m.a.s.l., dry mean annual rainfall ranging from 639 to 673 ml year^{-1}; Atsbi Womberta (Dega, highland) higher altitude 2300- 3200 m.a.s.l., moist mean annual rainfall ranging from 577 to 608 ml year^{-1}; and Raya Azebo (Kolla, lowland) lower altitude 500-1500 m.a.s.l., dry mean annual rainfall ranging from 633 to 770 ml year^{-1}. These agroecological classifications follow the standard set for Ethiopia by the Soil Conservation Research Programme (Hurni, 1986). However, no adequate number of trees could be found in the three land use categories in Irob and Atsbi Womberta. As a result, Hintalo Wajerat (Weyna dega) mid altitude 1500-2300 m.a.s.l., moist mean annual rainfall ranging from 516 to 716 mL year^{-1} and Alaje woredas (Dega) higher altitude 2300- 3200 m.a.s.l., moist mean annual rainfall ranging from 624 to 839 mL year^{-1} were selected as substitutes. Within the selected woredas, a village was purposively selected where *C. africana* could be found growing in the wild, farm lands and backyards in consultation with the woreda level forestry experts. Ten trees were selected randomly from each site of the wild, farm and grazing land and backyards. From each tree, 250 to 450 g mature fruits were collected, labelled, and placed in a cooler (which had an average of 4°C) for transport. The transport from Laelay Maychew and Raya Azebo took 24 h from collection to placement in the laboratory, and that of Alaje and Hintalo Wajerat arrived in the laboratory 5 h after collection. On the same day of arrival, the size, colour and weight of 10 representative fruits from each tree was measured. Two representative fruits were taken in triplicate for the moisture level and ash content determination. The whole fruit and fruit stones were also separated out and ashed for ash content determination. The reminder of the fruit was placed in a refrigerator (4°C) until processed. Within two to three days (stored at 4°C), fruits from each tree were homogenized. For homogenization, initially the fruit cap was removed; then the fruit skin was removed. Following this, the sticky flesh was dissolved into a specified amount of water (50-150 mL depending on number of fruits collected and fruit flesh size) and by blending it with an egg whisk. When the stone and flesh are separated, the skin is placed into the dissolved fruit flesh and blended into a homogenized fruit pulp paste.

Analytical methods

The size, colour, weight, moisture and ash were determined on individual fruits, while TP, FRAP, and vitamin C values were determined from the homogenized samples. As the homogenisation process involved dilution, TP, FRAP and vitamin C values were calculated back to discount the dilution. The principles followed in the analytical measurements were the following:

1. Antioxidants: 3 g of the homogenate was extracted in 30 mL of methanol and the antioxidant levels were determined by ferric reducing activity power (FRAP), and total phenols (TP) using Folin Ciocalteu's reagent. For both analysis, the Konelab 30i outline and method was followed (Volden et al., 2008; Zargar et al., 2011).
2. Size: the size was measured on both diagonal and vertical directions of the fruit (Bertin et al., 2009). This was done using a micro-calliper.
3. Colour: the colour was initially measured using a colour chart from the Natural Colour Systems (Hård and Sivik, 1981). The Natural Colour Systems colours were then converted to the CIE L*a*b* colour (Osorio and Vorobyev, 1996; Özkan et al., 2003) reading using a Minolta colour meter.
4. Weight: the weight of a selected representative 10 fruits was measured in grams using a portable digital balance with a sensitivity of 0.001 g (Ercisli and Orhan, 2007).
5. For vitamin C measurement 2,6-dichloroindophenol titrimetric method using oxalic acid as extractant was used, AOAC 967.21 was used (Hernández et al., 2006) .
6. Ash: As separating the flesh and the stone without dilution was difficult, ashing was done on the whole fruit and on the separated out stones. The overall procedure followed the AOAC 940.26 standard (Horwitz and Latimer, 2005).

The overall experimental setup gave a nested or hierarchical design of the four weredas, with three land uses and ten replicas. Each laboratory analysis was measured with three parallels. The results were aggregated per tree. To test for land use (inter population), variances and agroecological (intra population) variances, the fully nested ANOVA was used (Minitab 16.1, USA). The FRAP and TP means where tested for grouping and ranking using Tukey's tests. Further investigation was done using a Principal Component Analysis (PCA, Unsrambler 10X, USA and PAST (Hammer et al., 2001)), to test the relationship between the FRAP and TP laodings and agroecology. Another set of PCA was applied to test the relationship between FRAP and TP across agroecology and land use. This relationship was further explored by making a correlation matix (Minitab 16.1, USA).

RESULTS AND DISCUSSION

Fruit physical and chemical properties

The mean, standard error, minimum, median and maximum values of the FRAP and TP, both on fresh fruit (FW) and dry weight (DW) basis, are presented in Table 1.

The antioxidant levels in Table 1 show the measured values. There is a difference between the fresh and dry weight FRAP and TP values because the fresh fruit contained a lot of moisture with a mean of 56.89%. The FRAP average is comparable to that found from the bark extract in a similar species *Cordia dichotoma* bark, with 22.8 mg mL^{-1} TE on a dry weight basis (Ganjare et al., 2011). The average total phenol values (DW) are at least 5.7 times higher than fruit extract found in a similar species, *Cordia myxa*, with a variation found in the literature of 373.9-400 mg 100 g^{-1} GAE (Aberoumand and Deokule, 2009b; Aberoumand, 2011b; Souri et al., 2008). TP values in fresh fruits are comparable with that found in *Cordia exaltata* fruit with 190 mg 100 g^{-1} on a FW basis (Silva et al., 2007). To date, there is no daily requirement set for the consumption of antioxidants and total phenols. The American average daily intake of total phenols has been set to 450 mg GAE (Chun et al., 2005), and the Mexican average daily intake of antioxidants is 170.2 - 240.2 mg trolox equivalents day^{-1}, which is stated to be similar to 222-1004 mg GAE per day as found in Spanish Mediterranean diets, which is used as a reference for European countries (Hervert-Hernández et al., 2011). Taking these figures as bench marks, on the one hand, these antioxidant levels are too low for daily intake levels to be reached as 5222 g would be needed to reach the American recommended values. On the other hand, the total phenol content is high enough to meet the American and Mexican/Spanish Mediterranean daily intake levels

Table 1. Basic statistical results of the FRAP and TP measurements on both fresh (FW) and dry weight (DM) basis, and other basic fruit parameters measured.

Variable	Mean	SE Mean	Minimum	Median	Maximum
FRAP FW (mg 100 g^{-1}) TE	4.6	0.2	1.1	4.2	10.4
FRAP DW (mg 100 g^{-1})	30.8	1.45	8.7	27.8	78.5
TP FW (mg GAE 100 g^{-1})	264.1	12.2	70.5	248.5	687.9
TP DW (mg GAE 100 g^{-1})	2317.0	104.0	578.0	2215.0	4980.0
Ash whole fruit (%)	2.00	0.02	1.62	1.97	2.38
Average size (cm)	1.33	0.02	0.90	1.30	1.76
Moisture (%)	56.89	0.64	41.94	58.15	74.97
L (L scale)	31.48	0.22	25.08	31.42	43.71
a (a scale)	3.37	0.27	-5.97	3.43	9.87
b (b scale)	31.20	0.32	20.36	31.12	49.81
Weight (g)	15.34	0.50	6.60	14.00	33.70
Vitamin C (mg/100 g FW)	9.07	0.25	4.96	8.25	18.93
Vitamin C (mg/100 g DW)	20.20	0.31	14.15	19.77	30.38

FRAP = Ferric reducing activity power, TP = total phenols, TE = TROLOX equivalent, GAE = gallic acid equivalent.

Table 2. Nested ANOVA analysis of the FRAP and TP values of *C. africana* fruits.

Variable	Tested parameter	DF	Variance explained	F	P	Significance level
FRAP (DW)	Agroecological	3	10.83	4.54	0.04	*
	Land use	8	0.29	1.03	0.42	ns
TP (DW)	Agroecological	3	21.62	4.17	0.05	*
	Land use	8	13.99	3.17	0.00	**

FRAP = Ferric reducing activity power, TP = total phenols, dry weight (DW), * = significant at 95 %, ** = significant at 99% and ns = not significant.

by consuming 170.4 g. The fruiting season lasts on average for three months, as each tree has a different time of fruit maturation, and per tree fruits have different times of maturation. Assuming people consume the fruit during the fruiting season, it helps them to meet the daily recommended rates of total phenol need. On average people will eat about 100 g of the fruit at any given time, unless they are using it for treating gastro-intestinal illnesses, for which they would consume about 750 g at one time.

The ash content was 2 ± 0.02%, lower than that reported by Murray et al. (2001) (5.1 to 7.8% for *Cordia sinensis*) Aberoumand and Deokule (2009a) (6.7and 6.7 + 0.80%) and Aberoumand (2011a) for *Cordia myxa*. The average fruit diameter was 1.33 cm with an average moisture content of 56.89%. The average colour is light yellow (L 31.48, a 3.37 and b 31.2). The weight of the 10 representative fruits sampled was on average of 15.34 g. The fresh weight vitamin C was found to be 9.07 mg 100 g^{-1} fruit. This value is similar to that found in banana and apples (Planchon et al., 2004; Wall, 2006). According to the FDA guidelines, this value meets 15.12% of the daily required vitamin C levels for an average adult and according to FAO/WHO guidelines, this value meets 30.23% of the daily requirements (FAO/WHO, 2002; Food and Drug Administration, 2011).

Looking at the relatively good content of total phenols and vitamin C, it is obvious that this fruit is a nutritionally important fruit, with a limited range of use. Taking into account the benefits of antioxidants and vitamin C, it is clear that work is needed in the promotion and popularisation of this fruit. It is also clear that there is need for further study on its other nutritional benefits, processing and marketing potential to aid its promotion. The high variation in its size and weight also shows that there is great variation, which has implication on selection of the fruit source for promotion. As it grows in most parts of Africa and the Middle East its use and promotion has a wider significance than that of the studied area.

Fully nested ANOVA, principal component analysis (PCA) and correlation results

As the experimental setup had four agroecological zones and three land use systems, from which 10 trees were selected randomly, the experimental setup fits best to the nested or hierarchical design. ANOVA for a fully nested design was run and the results are presented in Table 2.

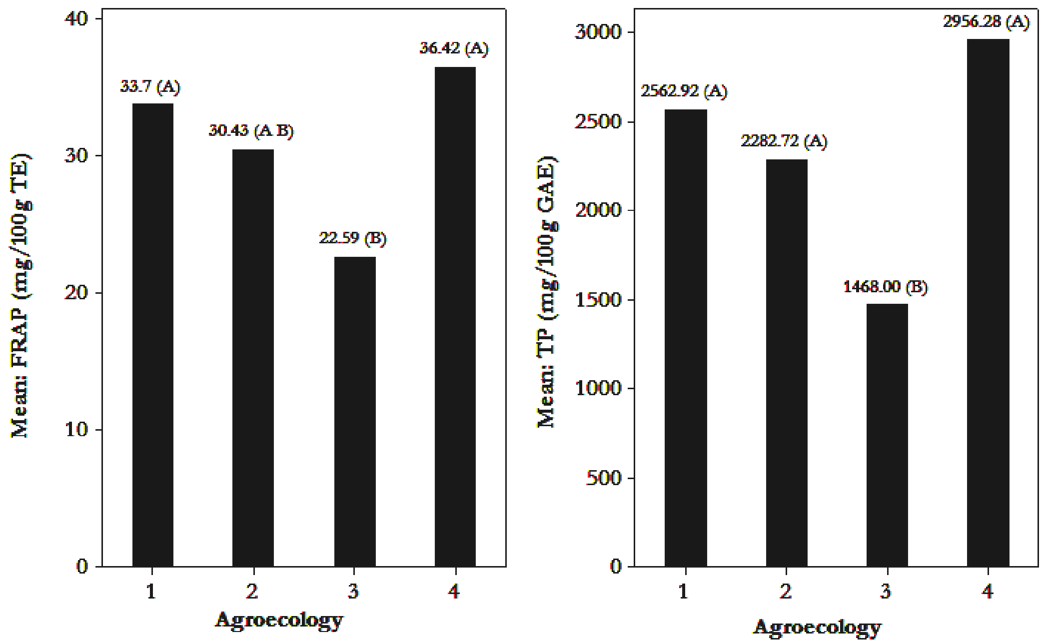

Figure 2. Tukey's ranking and grouping of mean values for FRAP and TP (based on dry weight (DW) across agroecology. 1 = highland, 2 = moist mid altitude, 3 = dry mid altitude, 4 = lowland.

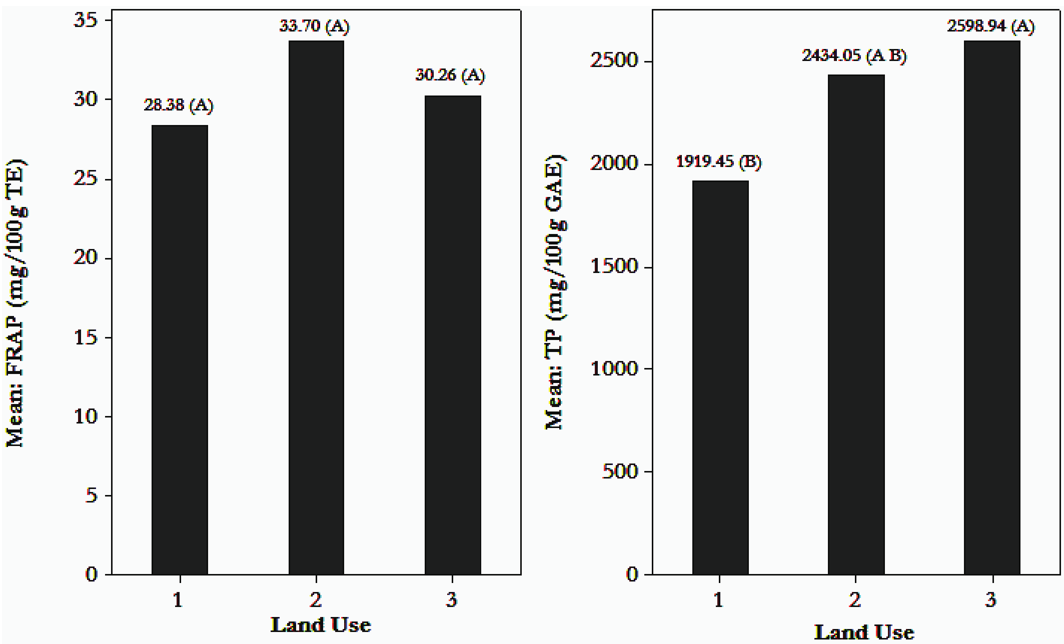

Figure 3. Tukey's ranking and grouping of mean values for FRAP and TP (based on dry weight (DW)) across land use. 1 = backyard, 2 = farm land, 3 = wild.

As can be seen in Table 2, both the FRAP and TP values were significantly different for the different agroecologies tested. The FRAP values were not significantly different from each other across the different land uses, while the TP values were significantly different across the different land uses. All the parameters were also tested for ranking and grouping using Tukey's test. The results are summarised in Figures 2 and 3. As can be seen in Figure 2,

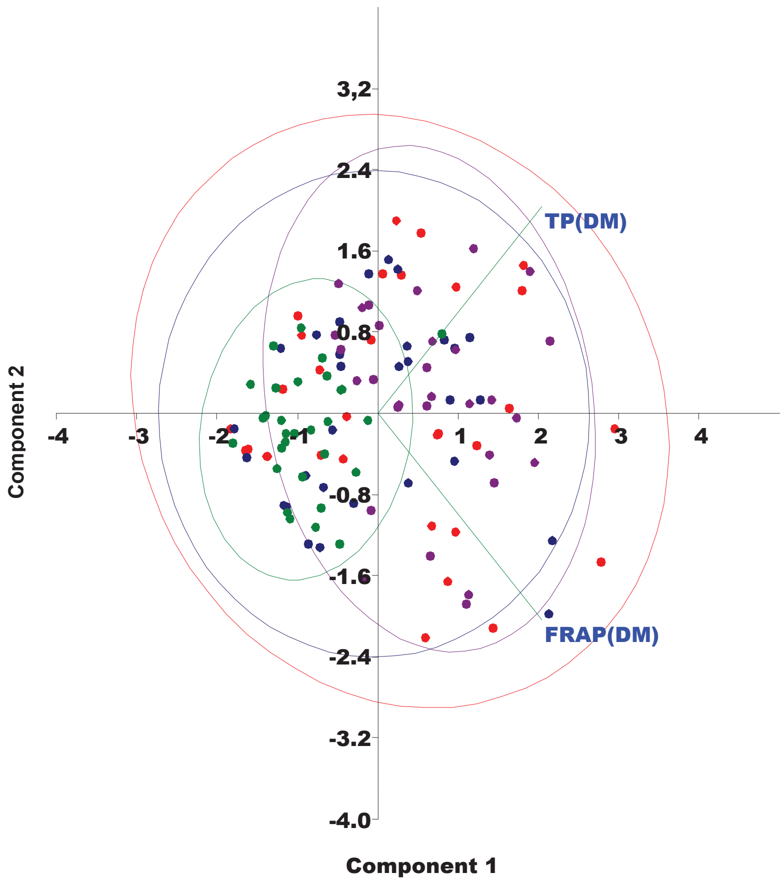

Figure 4. PCA of FRAP and TP values based on agroecology. Red = higher altitude, dark blue = moist mid altitude, green = dry mid altitude, purple = lower altitude.

the lower altitude site had the highest values for both FRAP and TP, while the mid altitude dry site had the lowest values with significant differences between these highest and lowest values. The lower altitude area has higher temperatures as compared to the other sites, and these results are in agreement with a strawberry study, where it was noted that both phenolic content and antioxidant content of the fruits increased with increasing growing temperature (Wang and Zheng, 2001).

The FRAP values in Figure 3 were not significantly different across land use in both the nested ANOVA and Tukey's tests. The TP values showed a significant difference with highest values measured for fruits from the wild and lowest values for fruits from the backyard, while that in the farm land was in between. As the trees in the backyards are purposefully selected, and those from the farm land are semi purposefuly selected, one possible explanation for this difference could be a factor of selection resulting with trees with special traits. Breeding and cultivar (genetic variety, provenace) development starts with this, and several studies have shown that cultivars have a significant effect on the total phenol values (Cordenunsi et al., 2002; Howard et al., 2003; Kotíková et al., 2011; Wicklund et al., 2005). Though there have not been studies showing that *C. arifcana* has specific cultivars, studies on its genetic variation within provenances (specific geographical location) have shown that there is a high variation (Derero et al., 2011; Loha et al., 2006, 2009). Another reason can be difference in the micro climate of these land uses, with the wild predominantly being marginal where environmental stress is highest, and the backyard being the most conducive with watering, organic matter and ash application creating a difference in the stress levels in the trees. The farm lands are flat and more fertile than the wild areas. In relation to this, several studies have shown that fruits grown under stressful conditions produce higher levels of phenolic compounds (Oh et al., 2009; Tomás-Barberán and Espín, 2001; Yuri et al., 2009).

A principal component analysis of the agroecological groups was run for both FRAP and TP values as presented in Figure 4. As can be seen with respect to the principal components (PC) 1 and 2, the score of the

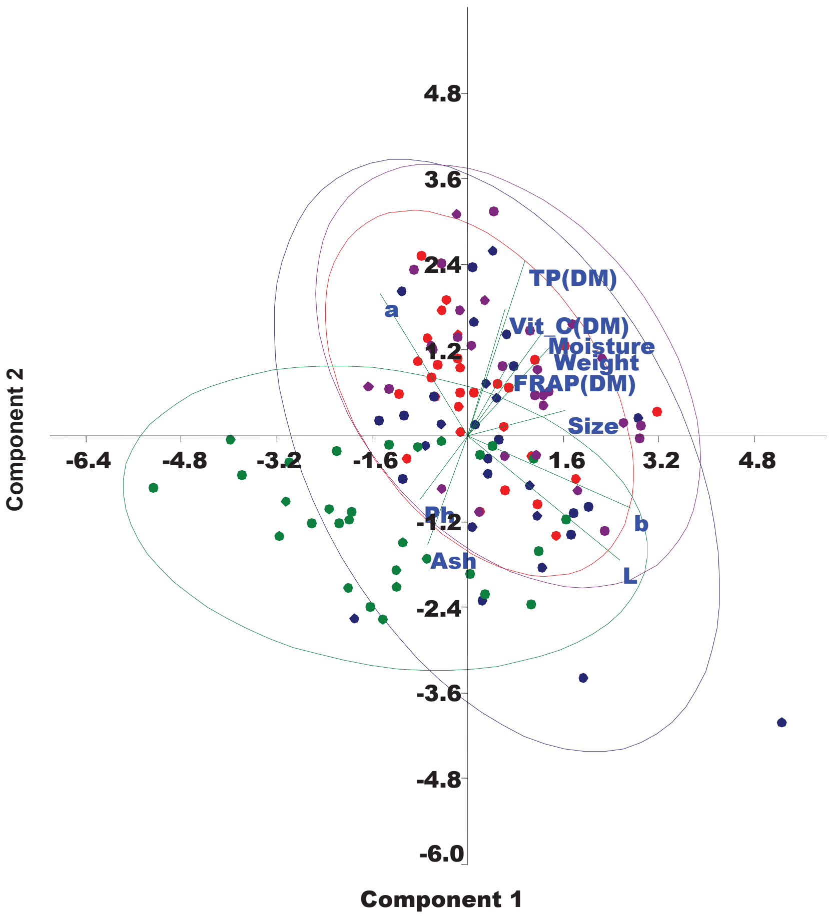

Figure 5. PCA of FRAP and TP and other related fruit parameters based on agroecology. Red = higher altitude, dark blue = moist mid altitude, green = dry mid altitude, purple = lower altitude.

higher altitude agroecology was more widely scattered, while they were narrowly scattered for the dry mid altitude agroecology. The loadings for FRAP and TP best explain the score of the lower altitude agroecology and least explain the score range of the dry mid altitude agroecology concurring with the ANOVA and Tukey's grouping results (Table 2, Figures 2 and 3). Another principal component analysis with agroecological and land use groups was run for both FRAP, TP and other related fruit parameters (Figures 5 and 6). The loadings for the first two principal components show that FRAP, TP, vitamin C, moisture content, weight and average size have a positive relationship, while whole fruit ash content have a negative relationship. The colour parameters L*a*b showed minimal relationship. With respect to the agroecological grouping (Figure 5), the scores of the higher altitude agroecology was the narrowest in scatter, yet the relationship it had with the loadings was similar with that of the moist mid altitude and lower altitude agroecologies. The scores of the dry mid altitude agroecology were least explained once again by the loadings for FRAP, TP, vitamin C, moisture, weight and colour axis a. This result shows a similar pattern as that of ANOVA and Tukey's grouping; where the dry mid altitude agroecology is separate (Figures 2 and 3).

Looking at the land use groupings of the scores (Figure 6), the backyard and farm land showed similar patterns. On the other hand, the wild land use was slightly different in that it had more response to the colour axis of L*a*b values and was less explained by the other loading directions. This also shows a similar pattern as that of ANOVA and Tukey's grouping, with the wild score being separate (Table 2, Figures 2 and 3).

Following the PCA analysis, a correlation relationship with FRAP and TP of a few related fruit parameters was run to further investigate the observed relationships. The correlation matrix showed a similar picture as that of principal component analysis in Figures 5 and 6, with both positive and negative relationships with the selected fruit parameters except for that of L*a*b*. The FRAP

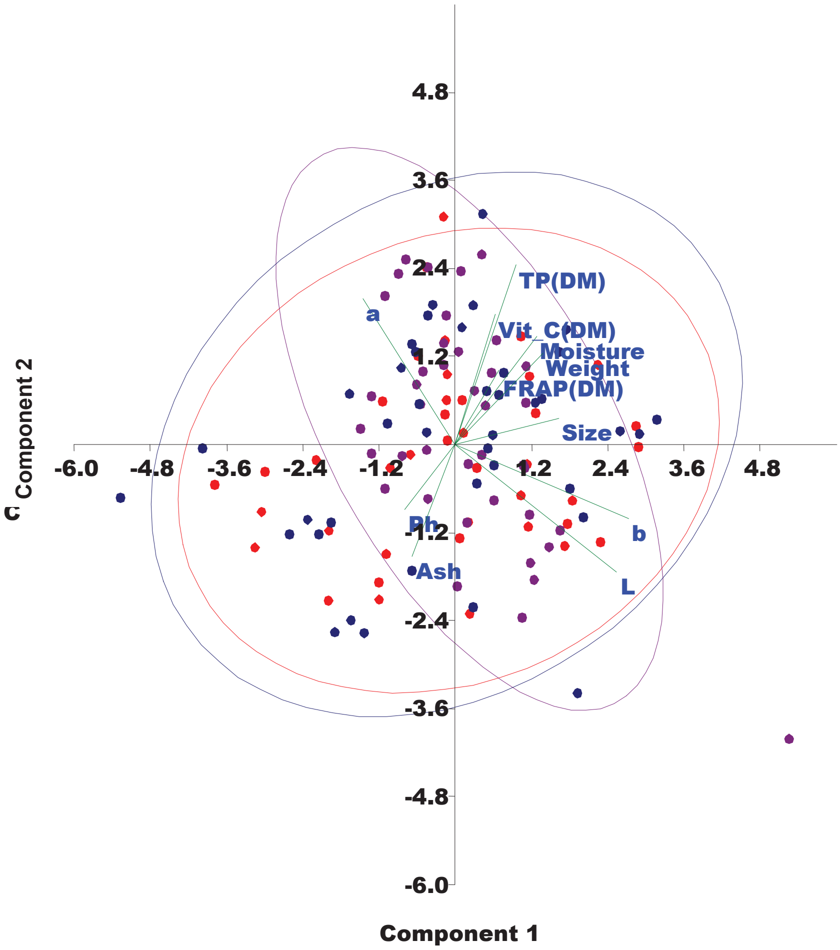

Figure 6. PCA of FRAP, TP and other related fruit parameters based on land use. Red = backyard, dark blue = farm land, purple = wild.

values were only correlated significantly with total phenol and fruit moisture levels, while the TP values are significantly correlated with the moisture, weight, vitamin C and fruit ash content. However, it needs to be noted that though there was a significant relationship considering the p values, the Pearson's correlation coefficient was very low. The correlation relationship of TP with fruit ash content was negative as indicated by the PCA in Figures 5 and 6. The positive relationships could be explained as vitamin C is an antioxidant and the weight and moisture content are indicators of better fruit growth. The negative relationship can be explained by the fact that phenols are acidic, and acidic compounds have lower pH. With respect to the relationship with the fruit ash content, the highest content of total phenols was found in the wild which are marginal lands. The soil fertility in these areas is lower, and previous studies have shown that soil fertility and mineral contents are related (Havlin et al., 2009; Lucas et al., 1942).

These results have implications for the use and promotion of this fruit. Currently, the fruits is consumed locally and sold in local markets (Demel and Abeje, 2005). Currently, in most parts of Ethiopia and Tigray there are massive afforestation efforts underway, that if managed properly have a great potential to contribute to improved food security, poverty alleviation and environmental rehabilitation (Egziabher, 2006; Fentahun and Hager, 2009; Gebrehiwot and Headquarters, 2004; Mengistu et al., 2005; Tewolde-Berhan et al., 2002; Yami et al., 2006). This study has shown that the fruit is useful and beneficial for health, and the TP values were highest in the wild. The promotion and wider use of the fruit can be achieved through its incorporation in the existing enclosure, communal forestry, and hillside distribution efforts. In addition to this, efforts need to be put in place to promote and market the fruit.

Conclusion

Cordia africana is a fruit with good quantities of TP-total phenol antioxidants. The antioxidant content tested with the FRAP, was not high. Both FRAP and TP values showed variation across agroecology, and only the phenolic content with variation across land use. The phenolic content is also strongly related to the FRAP, moisture content, weight, vitamin C and fruit ash contents.

The significance of these results is in its implication for use. These fruits are consumed by the local community and are sold in local markets. As these antioxidants and vitamin C tested are known to have beneficial effects towards health, the continued consumption of these fruits in Tigray is highly recommended. As the fruit is known to grow in most parts of Africa and the Middle East, its use needs to made known and the fruit needs to be promoted. Further study on its overall nutritional value, processing potential and marketability will help in the promotion of the fruit. As the size and weight was also found to have great variability, care needs to be taken to select appropriate seed sources for promotion. With the growing afforestation efforts in the region, this species should be given focus as its TP values where the highest in the wild, which represents the afforestation sites. Understanding their use will help in the up scaling of their use and marketing.

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PAPER II

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Article

Nutritional Composition of *Cordia africana* (Lam.) fruit in Different Agroecological Zones and Land Uses

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Abstract: In the world we find a lot of lesser known but locally used plants and fruits. These indigenous fruits and plants make substantial contributions to food security and nutrition. *Cordia africana* (Lam.) is a small fruit eaten in Ethiopia and Africa. The fruit was tested for its moisture content, total soluble solids (30% fruit in water), pH (30% fruit in water), total acidity (30% fruit in water), ash, crude protein, Ca, Cu, Fe, K, Mg, Mn, Na, P, Zn, vitamin C and A, size, mass and colour across four different agroecologies and three land uses. The consumption 600 grams of this fruit will meet at least half the daily the nutritional requirements of protein, calcium, copper, iron, potassium, magnesium, manganese, phosphorous, vitamin C and vitamin A. FAO notes chronic iodine, vitamin A and iron shortage in Ethiopia. *C. africana* fruit can be used as a partial source of vitamin A and iron. The tested nutritional aspects of the fruit were found to vary more with agroecology than with land use. In conclusion, it can be noted that *C. africana* is a nutritious fruit, which should be promoted in planting, processing, marketing and consumption throughout Africa.

Keywords: *Cordia africana* fruit; agroecology; land use, calcium, iron vitamin A and C.

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1. Introduction

In the world we find a lot of lesser known but locally used plants. These indigenous fruits and plants make substantial contributions to the food security, improving health and nutrition, medicinal treatment, income generation, cultural heritage, and environmental protection both in drought periods and normal seasons (Akinnifesi et al. 2006; Bharucha & Pretty 2010; Hernández et al. 2006; Jaenicke & Höschle-Zeledon 2006). In a review of several studies on a global scale, looking at the importance of wild plants and animals an average of 120 species were found to be used per community. However due to globalization and industrialization, diets are being modernized with less and less emphasis being given to these food sources and are slowly replaced by commercialized, cultivated and exotic foods. This does not give a proper replacement nutritionally (Bharucha & Pretty 2010). Thus it can be seen that these plants need to be given stronger focus. One such plant is *Cordia africana* (Lam.), which is consumed and marketed in Tigray, Northern Ethiopia and other parts of the country.

C. africana is found wide spread in the Middle East, West, East, and Southern Africa. It is known by the name Sudan teak, East African Cordia, large-leafed Cordia, and Sebastian fruit (ICRAF 2008). There are not studies showing the production capacity of the trees, but from personal observation, a mature tree can produces up to 15 kg of fruit. In Tigray *C. africana* fruit is eaten by the local community during its fruiting season of April to June, at a time when most fruit trees don't produce fruit and food is running low in the farming families. The tree is also known to produce fruit in drought years as the tree has deep roots. It is collected and eaten by shepherds and children when found in the wild, and collected, and eaten or sold by women and children when grown in farms or backyards. Generally the fruit is eaten fresh, however traditionally the fruit is also dried and kept for use during off-season.

Fruit characteristics and nutritional composition is known to vary according to cultivar (genetic variance, provenance) (Cordenunsi et al. 2002; Davies et al. 1981; Diamanti et al. 2013; Wicklund et al. 2005), ripening stage (Al-Maiman & Ahmad 2002; Davies et al. 1981; Vendramini & Trugo 2000), various environmental conditions such as temperature, rainfall, soil, water availability, exposure to the sun, and altitude and ultraviolet radiation (Albert et al. 2011; Ballester et al. 2011; Bhattacharya & Sen-Mandi 2011; Borochov-

Neori et al. 2011; Jackson & Lombard 1993; Jogaiah et al. 2012; Trought & Bramley 2011), management and land use related selection criteria applied by local communities (Alcobendas et al. 2012; Khan et al. 2010; Lescourret et al. 2011). In areas where fruit trees are semi-domesticated, trees located near homes and more easily accessible sites are shown to have some form of selection in contrast to those growing in the wild (Khan et al. 2010). The diversity of *C. africana* has been observed by looking at genetic markers (Derero et al. 2011), seed physical characteristics and germination time (Loha et al. 2006; Loha et al. 2009). In these studies, they found that the populations of *C. africana* investigated had more genetic diversity within rather than between populations. Within Tigray area in Ethiopia, *C. africana* is found to grow in different land use and agroecological conditions. It is an indigenous tree (natural forests, community afforestation sites, and church forests), farm lands, grazing lands and people's backyards (home gardens) within the altitude range of 500 to 2700 m.a.s.l. (ICRAF 2008; Obeng 2010). The land use classification was used based on closeness to residence and ownership, as closeness was assumed to influence the selection of genetic material as seen for Jackfruit in Bangladesh (Khan et al. 2010).

The agroecology in Ethiopia is classified based on altitude and rainfall (Hurni 1986). This is because daylength is more of less constant and only temperature and rainfall very. The temperature and rainfall vary on altitude and the direction of the rain carrying clouds, and the rain carrying cloueds come from the Atlantic from June- September and Pacific from February-April. *C. africana* is found in areas of Tigray with moist highland, at an altitude of 2300 to 3200 m.a.s.l. and rainfall of 900 to 1400 ml year^{-1}; dry mid highland with altitude 1500 to 2300 m.a.s.l. and rainfall of less 900 and moist mid highland at the same altitude but with rainfall of 900 to 1400 ml year^{-1}; and dry lowland with an altitude less than 1500 m.a.s.l. and rainfall less than 900 ml year^{-1}. The objective of this study was to determine the nutritional composition of *Cordia africana* fruit within the context of the typical Tigrian diet, as found in the different land use and agroecological zones.

2. Material and methods

2.1. Corida africana fruit sampling

The fruit sampling tried to take into account the different land use and agroecological zones. The existing study areas where *C. africana* was found were divided into four agroecological zones and three land use systems within the four agroecological zones. For the selection of the specific study sites, a woreda (second smallest level of administration in Ethiopia) was randomly selected from each of the agroecological zone so as to represent the agroecological area. **Figure 1** shows an altitudinal map of the Tigray Regional State showing the three different agroecological zones based on altitude. Estimated rainfall data were added to this map in order to determine the selection of the four woredas. The four randomly selected woredas are shown in **Table 1**. However, no adequate number of trees could be found in the three land use categories in Irob and Atsbi Womberta. As a result, two other weredas were selected as substitutes. Within the selected woredas, a village was purposively selected where *C. africana* could be found growing in the wild, farm lands and backyards in consultation with the woreda level forestry experts. Ten trees were randomly selected from each site of the wild, farm and grazing land and backyards. From each tree, 250 to 450 g mature fruits were collected, labelled, and placed in a cooler (which had an average temperature of +4°C, during transport to the Mekelle University lab. The evaluation of the ripening based on colour but also firmness and splitting of the skin due to precipitation, determined harvest of the fruits. Local boys were employed to select the best fruit bunches to bring down, as they knew the trees and the fruits best. The transport from Laelay Maychew and Raya Azebo took 24 hours from collection to arrival of the lab, and that of Alaje and Hintalo Wajerat arrived 5 hours after collection. Table 1 shows a summary of the selected sites.

Figure 1. Map of selected *woredas* in Tigray, Ethiopia, East Africa, showing their relative location and altitude. Generated on the free DIVA-GIS software, (Hijmans et al. 2012).

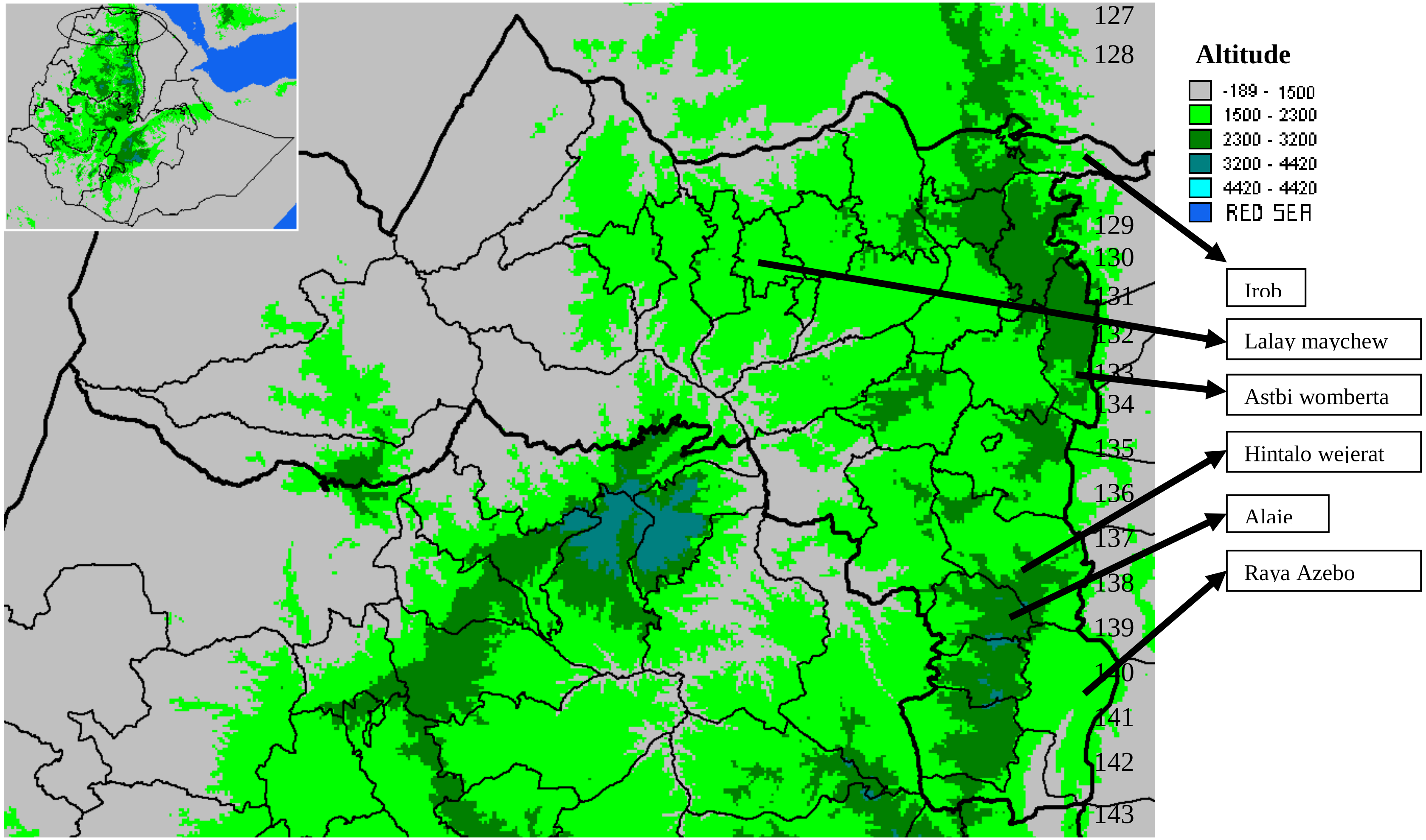


Table 1. Sampling method for site selection, with three land use (LU) within each of the four agroecology zone (AZ)

No	Name of selected woreda	Agroecological characteristics	No	Land use	Tree selection for fruit and other criteria
AZ 1	Atsbi Womber replaced by Alaje	Moist high altitude	LU 1	Backyard or home gardens	Intentional selection of what grows
AZ 2	Irib replaced by Hintalo Wajerat	Moist mid highland	LU 2	Farm land or grazing land	Partial selection of what grows
AZ 3	Laelay Maychew	Dry mid highland	LU 3	Wild (natural forests, community afforestation sites, church forests)	No selection of what grows
AZ 4	Raya Azebo	Dry lowland			

2.2. Sample preparation and measurements

After fruit collection, on the same day of arrival, the size, colour, firmness and mass of 10 representative fruits from each tree was evaluated. All the measurements were done in triplicates. Two fruits were taken for the moisture content determination. The two whole fruit and two separated out fruit stones were used for ash content determination. The rest of the fruits were placed in a refrigerator (+4^{O}C) until processed two-three days later. For vitamin C determination, approximately 30 g of fruit was taken and blended with oxalic acid. Two fruits from the remaining fruits were weighed, and flesh and stone separated to determine the flesh to stone relationship. For the remaining analysis, the fruits selected from each tree were homogenized. For vitamin A analysis and the repeat measurement of protein undertaken in 2012 fruits were homogenized per land use in the different agroecologies so as to reduce samples size and cost of analysis. For homogenization, the fruit cap was initially removed; then the fruit skin. Following this, the sticky flesh was dissolved into a specified amount of distilled water (50-150 ml depending on number of fruits collected and fruit flesh mass) by blending it with an egg whisk. When the stone and flesh were separated the skin was mixed with the dissolved fruit flesh and blended. The total soluble solids, pH, and total acidity were measured at 30% fruit concentration in distilled water due to the viscous fruit pulp. The results are presented at 30% fruit concentration as solute availability, acidity and pH depend on a lot more than just fruit concentration (Bates 1954; Harvey 1920). Vitamin A, total soluble solids, pH and total acidity was measured from liquid homogenized fruit pulp paste. Protein, mineral and trace element analysis, the fruit pulp paste was further homogenised with an ultra-torax blender and freeze dried as the analytical methods used required small samples.

2.2.1. Physical description of the fruits

- Size: the size was measured on both diagonal and vertical directions of the fruit (Bertin et al. 2009). This was done using a micro-calliper.
- Colour: the colour was initially measured using a colour chart from the Natural Colour Systems (Hård & Sivik 1981). All the colour measurements were done by one person to avoid bias. Fruits that had different colours, where applicable the dominant colour was considered. When the colours were more or less equally present, an average colour in between was estimated. The Natural Colour Systems colours were after the determination from the fruits converted to the Commission Internationale de l'Eclairage (CIE) L*a*b* colour (Osorio & Vorobyev 1996; Özkan et al. 2003) using a Minolta colour meter reading the Natural Colour System colour charts.
- Firmness: the firmness was evaluated using personal judgment and classes of Medium, Soft, and Firm fruits were determined.
- Mass: fruits were measured in grams using a portable digital balance with a sensitivity of 0.001 g (Ercisli & Orhan 2007).

2.2.2. Nutritional composition

- Ash: ashing of the whole fruit and separated stone was done using the AOAC 940.26 standard (Horwitz & Latimer 2005). The ash of the fruit flesh was determined by subtracting the ash from the stone from that of the whole fruit.
- Protein: protein was determined using dried material. Thus, the protein levels are presented in both the dry matter and fresh sample basis. The procedure followed was that of AOAC 2001.11 (Horwitz & Latimer 2005).'
- Moisture content: was determined using the AOAC 934.06 standard (Horwitz & Latimer 2005).
- Total soluble solids: was measured by preparing the samples of the 30% fruit in water homogenised material, then as explained in AOAC 932.12 standard (Horwitz & Latimer 2005), however the calculations were not necessary as the portable refractometer used gave readings already converted to ^{o}Brix.
- pH: the pH and temperature of the 30% fruit in water homogenised material was measured using a portable automatic pH meter.
- Total acidity: total acidity of the 30% fruit in water homogenised material was measured by visual titration following AOAC 920.92 standard (Cardwell et al. 1991; Horwitz & Latimer 2005).
- Vitamins: Vitamin C was measured following AOAC 967.21 standard with the Metaphosphoric acid–acetic acid solution replaced by 0.1% oxalic acid (Eleyinmi et al. 2002). Vitamin A was measured using the method where trans-β-carotene was extracted one time with ethanol: hexane (4:3 v/v) and two times with hexane. The

determination was carried out by reversed phase – high performance liquid chromatography with ultraviolet diode array detection (450 nm). For quantification, a 3-point calibration curve was used. The calibration standards used were pure compounds from Sigma, purity > 98 %. The purity of the standards for each calibration was determined by a series of spectrofotometric measurements (UV 340/455/483 nm) method described in DIN EN 12823-2:2000 (Bernhardt & Schlich 2006; Blake 2007; Szpylka & W. Devries 2005).

- Mineral and trace element analysis samples (Fe, Cu, Mg, Zn, Ca, Na, K) where all digested at 250°C with 75% (V/V) HNO_3 (Ultra Clave III from Milestone) and samples are measured with inductively coupled plasma atomic emission spectroscopy (Optima 5300 DV from Perkin Elmer) (Kira et al. 2004).

3. Results and Discussion

3.1. Physical characteristics

The physical characteristics are presented **Table 2**, where size colour, firmness and mass were measured.

Table 2. *C. africana* fruit physical characteristics.

Variable	Mean	Range
Average diameter (cm)	1.33± 0.02	0.90 - 1.76
Diagonal diameter (cm)	1.25±0.02	0.91 - 2.08
Vertical diameter (cm)	1.40±0.02	0.89 - 2.09
L* (L scale, 0 black and 100 white)	31.48±0.22	25.08 - 43.71
a* (a scale, - green and + red)	3.37±0.27	-5.97 - 9.87
b* (b scale, - blue and + yellow)	31.20±0.32	20.36 - 49.81
Firmness	Medium	
Mass of 10 fruits (g)	15.34±0.50	6.60 - 33.70

As can be seen in **Table 2**, the *Cordia africana* fruit was a small fruit, moderately soft and yellow to orange in colour when ripe. It had a sticky, acidic sweet fruit with a large stone. It is round and slightly larger in the vertical dimension. A high variability in size and mass was found for the fruits depending on growing site. A fully nested ANOVA analysis was applied to investigate this variation, and is presented in **Table 3**.

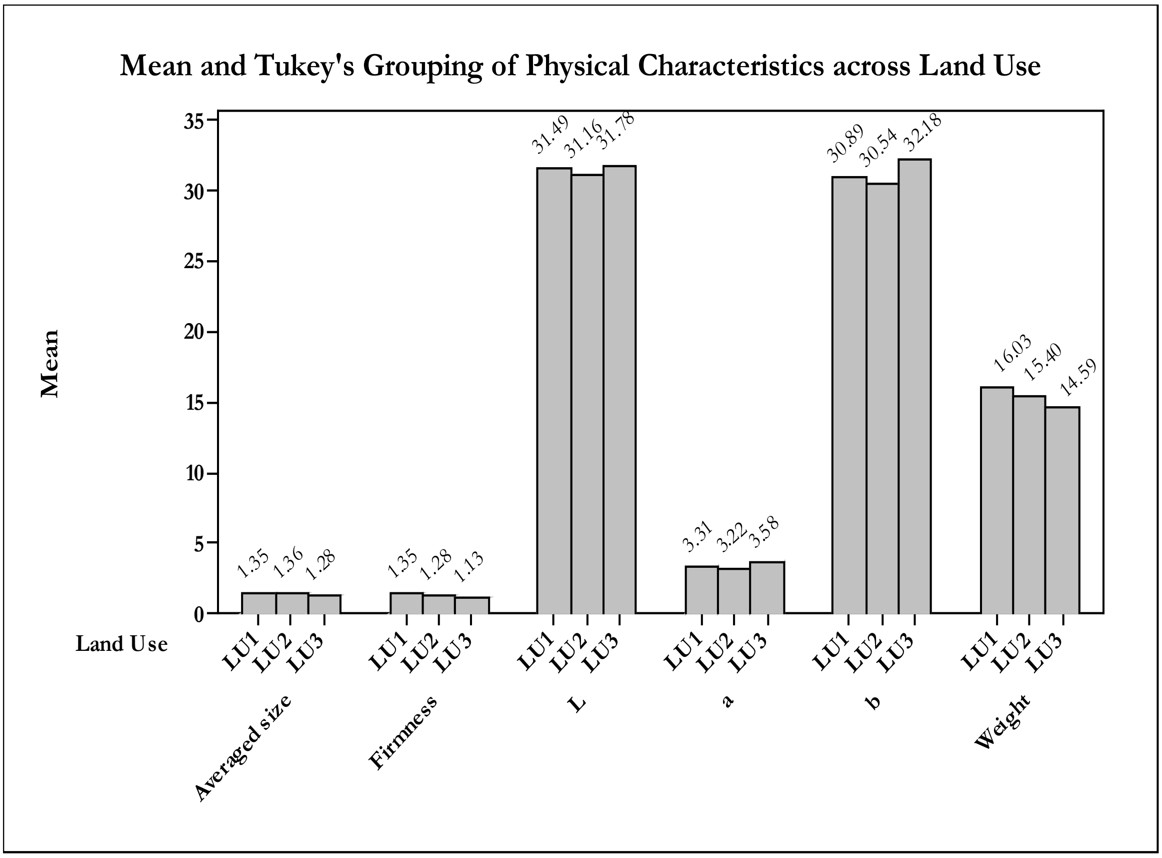
Table 3. Fully nested ANOVA analysis of the variation of physical characteristics of *C. africana* fruits across agroecology zones (AZ) and land use (LU).

Variable	Nesting parameter	DF	Variance component%	F	P	Sig
Average diameter (cm)	AZ	3	0.00	0.97	0.45	
	LU	8	35.92	6.61	0.00	**
Diagonal diameter (cm)	AZ	3	0.04	1.00	0.44	
	LU	8	33.63	6.07	0.00	**
Vertical diameter (cm)	AZ	3	0.00	0.96	0.46	
	LU	8	26.05	4.52	0.00	**
L* (L scale, 0 black and 100 white)	AZ	3	0.00	0.64	0.61	
	LU	8	5.00	1.53	0.16	
a* (a scale, - green and + red)	AZ	3	2.23	1.57	0.27	
	LU	8	2.20	1.23	0.29	
b* (b scale, - blue and + yellow)	AZ	3	7.63	2.15	0.17	
	LU	8	11.90	2.48	0.02	*
Firmness	AZ	3	12.27	3.64	0.06	
	LU	8	5.75	1.70	0.11	
Mass of 10 fruits (g)	AZ	3	19.97	3.22	0.08	
	LU	8	21.08	4.58	0.00	**

* Significant at 5% ** Significant at 1%

The analysis of variance across land use and agroecology showed significant variation only across the land use for the physical characteristics measured (**Table 3**). This is consistent especially for the fruit size and mass, as fruits found growing in the backyards and near water sources had larger fruits compared to the other sites. This is a good indication of how management can affect the fruit size. An overview of this variation is shown in **Figure 2**.

Figure 2. Mean values of physical parameters measured across the different land use. LU1= Backyard, LU2=Farm land, LU3= Wild.



As can be seen in **Figure 2**, the mean values progressively get smaller from backyard to farmland to wild land use systems. Similar to what was found in other studies environmental factors, management and genetic material selection favours the production of bigger fruits in the backyard (Alcobendas et al. 2012; Khan et al. 2010; Lescourret et al. 2011). To investigate any relationship the physical parameters may have, a Pearson's correlation was done, the results of which are presented in **Table 4**.

Table 4. Pearson's correlation matrix for the measured physical parameters.

	Average size	**Firmness**	**L***	**a***
L*	0.200*			
a*	-0.217*		-0.469**	
b*	0.200*	-0.221*	0.888**	-0.339**
Mass	0.427**			

* Significant at 5% ** Significant at 1%

Table 4 shows correlations of the physical parameters size, firmness and colour. The average size was the dominant physical parameter. As would be expected, size and mass are highly significantly related, and overall the colour was significantly correlated with size. The colour parameters were also correlated with each other at degrees from significant to highly significant. The firmness was significantly negatively correlated to the colour blue to yellow. This is probably due to the fact that the firmness set as medium was given "1" and soft was given "2", and fruits that were getting soft were also changing their colour to brown. As there is more blue in the brown colour the correlation indicated this. It is interesting that the browning was measurable on the b axis; this is due to the fact that the fruit is more yellow orange in colour when ripe.

3.2. Nutritional composition

The summarized values of the measured nutritional characteristics are presented in **Table 5**.

Table 5. Nutritional composition of *C. africana* fruits on a fresh (FW) and dry mass (DM) basis.

Variable	Mean (FW)	Mean (DW)	Range (FW)	Fruit (g) to meet daily recommended intake/*
Ash fruit flesh (%)	0.69±0.13		0.10 -1.86	
Protein 2011 (%)	7.28±0.27	12.90±0.53	2.18 - 15.29	687
Protein(2012) (%)	5.77±0.12	10.88±0.21	3.10 - 7.85	856
Moisture (%)	56.89±0.64		41.94 - 74.97	
Total soluble solids (%)	18.92±0.41		0.33 - 28.06	
pH	6.36±0.02		5.44 - 7.06	
Total acidity (% citric acid equivalent)	0.71±0.01		0.01 - 0.43	
Vitamin C (mg/100g)	9.07±0.25	20.20±0.31	4.96 - 18.93	662
Vitamin A (μg/100g)	733.00±80.60	1298.80±43.30	430.70 - 1272.00	409
Ca (mg/g)	1.90±0.11	4.03±0.13	0.27 - 6.88	526
Cu (μg/g)	5.88±0.28	13.82±0.70	0.50 - 18.70	340
Fe (μg/g)	28.40±1.98	64.98±4.04	4.00 - 144.20	633
K (mg/g)	18.38±0.74	40.76±0.84	3.98 - 45.60	190
Mg (mg/g)	1.02±0.05	2.19±0.05	0.19 - 2.72	392
Mn (μg/g)	3.77±0.22	8.05±0.33	0.30 - 14.10	530
Na (μg/g)	44.93±3.79	96.56±6.61	9.80 - 307.40	53416
P (mg/g)	1.37±0.06	3.20±0.13	0.22 - 4.92	729
Zn (μg/g)	11.47±0.69	26.74±1.49	1.10 - 42.30	1307

* Based on FDA standards of the United States of America (Food and Drug Administration 2011).

As can be seen in **Table 5**, the ash content was 2% which is lower than that found in Tanzania where a range of 5.1% to 7.8% was found (Murray et al. 2001). The protein value on the dry matter basis is similar to the values found in the same study, which was 12.6 to 15.2%. A species in the same genus ; *Cordia myxa* growing in Iran, was found to contain 20.15% protein with 32.2% total nitrogen (Aberoumand 2008). In other studies, other species of *Cordia*; *C. glabrata* in Brazil and *C. dichotoma* in India were reported to contain 0.273% and 0.02% protein (Duhan et al. 1992; Mayworm et al. 1998). Therefore, the values found for *C. africana* are in consistent with the range of the reported values of/in similar species. The moisture content of the fruit was 56.89%, which is lower than reported for *C. dichotoma* from India (74%) (Duhan et al. 1992).

In a study of a gum extract from the fruit of a plant in the same genus *Cordia gheraf*, the extract was also found to be highly viscous, though no study on the viscosity of *C. africana* was found. At concentrations of mass by volume of more than 3%, the mixture was found to be too thick to even measure. At 3% wv-1 the flow rate was mLs-1 was 0.96 and the viscosity in poise was 2.85 (Doharey 2010). *Cordia rothii* was also found to be sticky and thus useful as a tablet binder (Vidyasagar et al. 2011). The total soluble solid content was 18.92% for a 30% fruit-to-water juice which would make 63.07% through simple extrapolation. This value is similar to the values found in the studies by Murray et al. (2001). However, it must be noted here that this extrapolation is simply done for comparison and is not to be considered as the actual value as the ^{o}Brix composing solute relationship in dilution is not straight forward. The pH and total acidity shows that *C. africana* is slightly acidic. The presence of vitamin C from this study and Uronic acid as shown by Benhura and Chidewe (2002), can be part of the explanation for the slightly acidic nature of the fruit.

The fruit had 1.9 mg/g FW calcium which was higher than the 0.46 mg/g found for *C. myxa* (Aberoumand & Deokule 2009). The copper value was 5.88 μg/g is lower than that reported for *C. dichotoma* 6.67 μg/g(Valvi & Rathod 2011). The iron value was 28.40 μg/g and is less than 0.51 mg/g found for *C. myxa* (Aberoumand & Deokule 2009). The potassium value was 18.38 mg/g which is much higher than 7.83 mg/g found for *C. myxa* (Aberoumand & Deokule 2009). The magnesium value is 1.02 mg/g which is slightly smaller than 1.24 mg/g reported for *C. dichotoma* (Valvi & Rathod 2011). The manganese value is 3.77 μg/g which is smaller than 15.6 μg/g reported for *C. dichotoma* (Valvi & Rathod 2011). The sodium value is 44.93 μg/g is less than 1.62 mg/g found for *C. myxa* (Aberoumand & Deokule 2009). The phosphorus value is 1.37 mg/g larger than 0.02 mg/g reported for *C. dichotoma* (Valvi & Rathod 2011). The zinc value is 11.47 μg/g which is much smaller than 0.35 mg/g found for *C. myxa* (Aberoumand & Deokule 2009). Though the values found in this study are different from the values for the other species in the same genus, most of the values are similar.

Nutritionally based on the FDA standard (Food and Drug Administration 2011), the fruit is a good partial source of for protein, calcium, copper, iron, potassium, magnesium, manganese, phosphorus, vitamin C and vitamin A and a poor source of sodium and zinc. The vitamin C content is comparable to that found in bananas and apples (Planchon et al. 2004; Wall 2006). The vitamin A content was found to be less than apricot(Karabulut et al. 2007) yet higher than papaya studied in Thailand and India(Charoensiri et al. 2009; Rajyalakshmi et al. 2003). The fruit pulp was found to constitute 70% of the mass. Based on this, 600 grams of the fruit will meet at least half of all the above mentioned nutrients and vitamins except for sodium and zinc. FAO notes that in Ethiopia there is a critical nutritional shortage of iodine, vitamin A and iron (FAO 2010). The iodine content of the fruit was not measured, however the vitamin A and iron levels measured in this study are substantive, and consumption of 900 grams of fruit will meet the daily requirement. As 900 grams of this fruit is not usually consumed, the fruit can be recommended for use to meet part of the daily requirements.

3.2.1. Variation in the different agroecology and land uses

The experimental setup had four agroecologies and three land use systems from which 10 trees were selected randomly. The ANOVA results of the different parameters in the different agroecology and land use are presented in **Table 6**.

Table 6. Fully nested ANOVA analysis of the variation of chemical characteristics in fresh mass (FW) of *C. africana* fruits across agroecology (AZ) and land use (LU).

Variable	Nesting parameter	DF	Variance component%	F	P	Sign of variance
Ash content fruit flesh (%)	AZ	3	0.00	0.08	0.97	
	LU	8	0.00	0.63	0.75	
Protein 2011 (% FW)	AZ	3	0.00	0.55	0.66	
	LU	8	21.69	3.77	0.00	**
Protein 2012 (%FW)	AZ	3	47.11	3.67	0.06	
	LU	8	52.89	6.61	0.00	**
Moisture content (%)	AZ	3	60.12	14.68	0.00	**
	LU	8	10.22	4.45	0.00	**
Total soluble solids (%)	AZ	3	3.03	1.60	0.27	
	LU	8	3.00	1.69	0.11	
pH	AZ	3	16.82	10.07	0.00	**
	LU	8	0.00	0.67	0.72	
Total acidity (citric acid equivalent)	AZ	3	14.01	3.68	0.06	
	LU	8	7.90	2.01	0.05	*
Vitamin C (mg/100g FW)	AZ	3	53.85	64.25	0.00	**
	LU	8	0.00	0.55	0.81	
Vitamin A (µg/100g FW)	AZ	3	13.14	1.45	0,30	
	LU	8	86.86	0,00	0,00	**
Ca (mg/g FW)	AZ	3	21.97	4.19	0.05	*
	LU	8	14.30	3.24	0.00	**
Cu (µg/g FW)	AZ	3	16.37	4.09	0.05	*
	LU	8	8.39	2.12	0.04	*
Fe (µg/g FW)	AZ	3	22.13	38.03	0.00	**
	LU	8	0.00	0.23	0.99	
K (mg/g FW)	AZ	3	37.07	72.59	0.00	**
	LU	8	0.00	0.25	0.98	
Mg (mg/g FW)	AZ	3	30.38	20.70	0.00	**
	LU	8	0.00	0.67	0.72	
Mn (µg/g FW)	AZ	3	27.41	22.57	0.00	**
	LU	8	0.00	0.53	0.84	
Na (µg/g FW)	AZ	3	7.76	2.67	0.12	

	LU	8	5.26	1.60	0.13	
P (mg/g FW)	AZ	3	12.22	3.01	0.09	
	LU	8	10.47	2.36	0.02	*
Zn (µg/g FW)	AZ	3	30.31	7.73	0.01	**
	LU	8	7.28	2.17	0.04	*

* Significant at 5% level ** Significant at 1% level

The analysis of variance across the land use and agroecology as **Table 6** showed more significant variation across agroecology compared to land use with eleven to nine instances. Overall, when the physical characteristics of **Table 3** are also considered, there was a higher variation across land use than agroecology. Looking at the most important minerals and vitamins from the nutritional point of view, Fe, Ca and vitamin C varied significantly across agroecology, while vitamin A and calcium varied across land use.

A Principal Component Analysis (PCA) was applied to test the effect of agroecology (AZ) and land use (LU) further (**Figure 3** and **Figure 4**). **Figure 3** shows that the different land use does not separate, and its influence is not as pronounced as that of the agroecology, as can be seen in **Figure 4**. Also, the AZ 1 and 2 are more similar to each other than AZ 3 and AZ 4, which is not surprising as these agroecologies have geographical and geological similarities, with only difference in altitude.

Figure 3. PCA score plot of the different chemical parameters per land use.

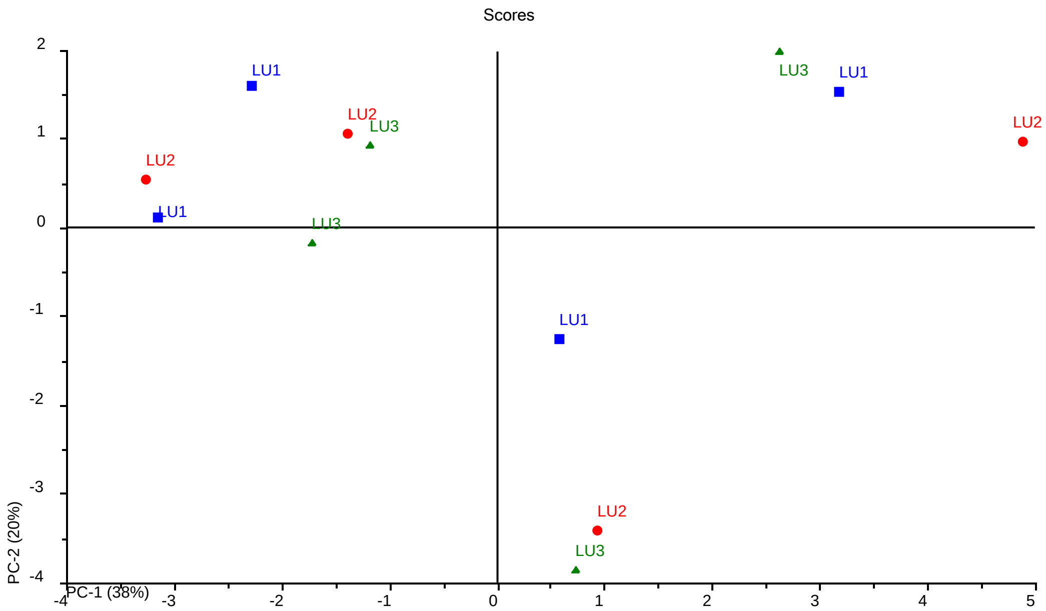
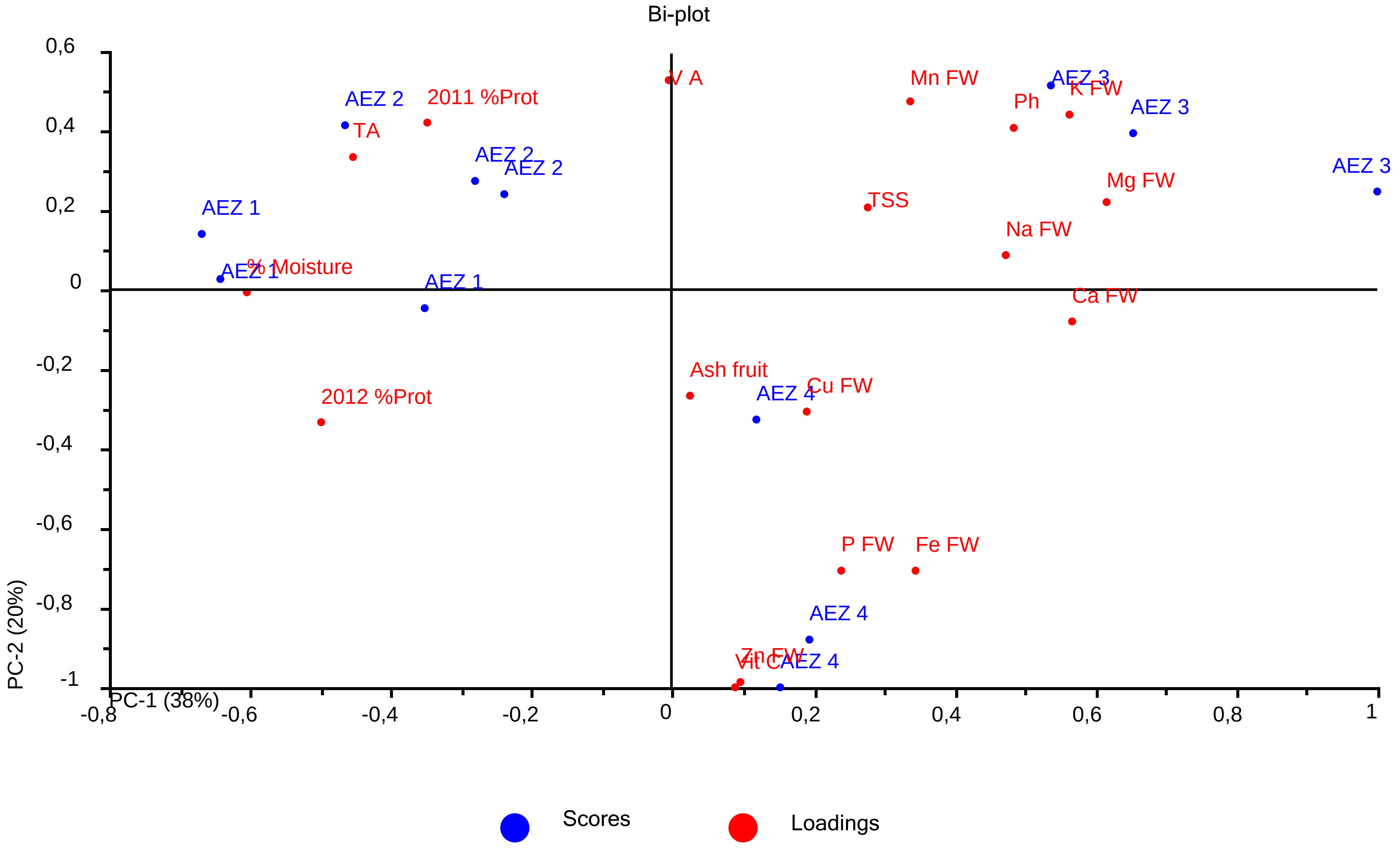


Figure 4 shows the interaction between the different parameters measured in the different agroecologies. Fruits from AZ 1 and 2 are more characterized by the total acidity, moisture and protein levels, though protein levels of 2011 define them better. AZ 3 is characterized by Ca, Mg, K, Na, Mn, pH, ash content and total soluble solid levels. AZ 4 is characterised by vitamin C and the mineral and trace elements Zn, P, Fe and Cu. Vitamin A was the measured parameter that had the least interaction with the agroecology groping. The mineral and trace elements were more important in AZ 3 and 4, why there

was such a clear division needs further investigation into the interaction of the agroecologies as related to the geology, soil and mineral and trace element availability.

350 **Figure 4.** Score and loading (bi-plot) of measured chemical parameters grouped into agroecology zones.



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An overview of the variation of the means across agroecology and land use of the nutritionally important variables Ca, Fe, vitamin A and C is presented in **Figure 5** and **Figure 6**. As can be seen in **Figure 5**, AZ4 (the dry lowlands) has the highest Fe and vitamin C, while AZ3 (dry mid altitude) has the highest Ca level. The high level of Fe and Ca can be explained by the presence of more Fe and Ca in the alluvial clay deposits found in the dry lowlands and the calcareous limestone based soils in the dry mid altitude areas(Albert et al. 2011; Davies et al. 1981). The high level of vitamin C in the dry lowlands can be explained by the fact that the sites where the fruits were collected had a more ground water available, and moisture availability has been shown to increase vitamin C availability (Nagy 1980; Patanè et al. 2011). The lowest Ca and Fe levels were found in AZ1 (moist highlands), while the lowest vitamin C level was found in AZ2 (moist mid altitude).

Figure 5. Mean values and Tukey's grouping for fresh mass Ca, Fe and vitamin C.

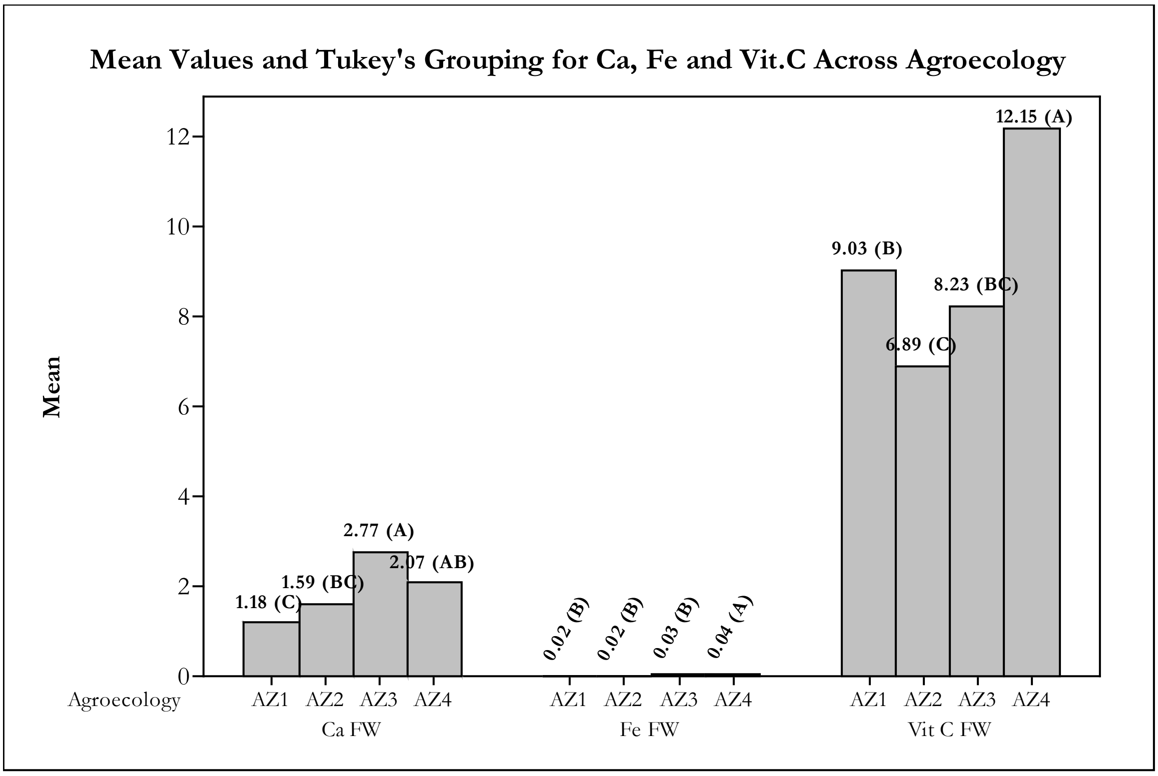
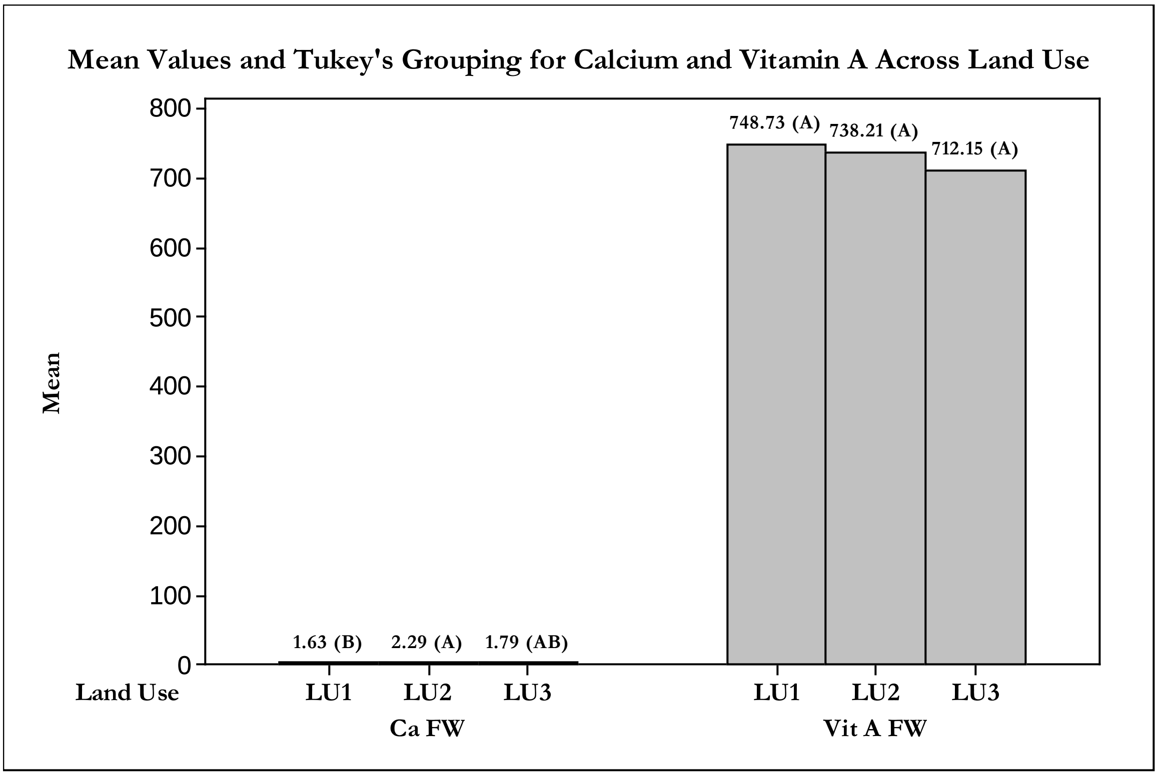


Figure 6 shows that the highest levels of vitamin A were found in LU1 (backyard) and of calcium are found in LU2 (farmland). The high level of vitamin A in the backyard could be due to the improved fertility of the land in the backyard as waste water, organic debris, ash from cooking fires, and similar materials are provided for the trees (Bénard et al. 2009; Lester et al. 2010). Similarly the higher Ca content of the fruits in the farm land could be as a result of the fact that the best and deepest soils are set aside for farming, and these probably have better Ca content (Albert et al. 2011; Davies et al. 1981).

Figure 6. Mean values and Tukey's grouping for Ca and vitamin A at a fresh mass (FW) basis.



3.2.2. Relationship of the different parameters to each other

To investigate the presence of any relationships between the different parameters, an overall Pearson's correlation was done. The results of the correlation run are summarised in **Table 7**

Table 7. Correlation matrix of the measured parameters.

	Total soluble solids (%)	pH	Total acidity (%)	Protein 2011 (%FW)	Moisture (%)	Ca (mg/g FW)	Cu (µg/g FW)	Fe (µg/g FW)	K (mg/g FW)	Mg (mg/g FW)	Mn (µg/g FW)	Na (µg/g FW)	P (mg/g FW)	Zn (µg/g FW)	Vit A FW (µg/100g FW)
Total acidity (%)	**0.433 ****	**-0.35****													
Protein 2012 (%FW)	**-0.218 ***	**-0.259****		**0.327****											
Moisture (%)			**0.211***												
Ca (mg/g FW)			**-0.244****		**-0.420****										
Cu (µg/g FW)			**-0.279****		**-0.287****	**0.667****									
Fe (µg/g FW)			**-0.200***			**0.396****	**0.418****								
K (mg/g FW)		**0.252****	**-0.254****	**0.198***	**-0.405****	**0.724****	**0.471****	**0.364****							
Mg (mg/g FW)		**0.188***	**-0.288****		**-0.383****	**0.796****	**0.504****	**0.338****	**0.863****						
Mn (µg/g FW)			**-0.227***	**0.210***	**-0.384****	**0.572****	**0.462****	**0.461****	**0.790****	**0.718****					
Na (µg/g FW)					**-0.238****	**0.563****	**0.486****	**0.512****	**0.531****	**0.500****	**0.424****				
P (mg/g FW)			**-0.271****	**0.251****		**0.438****	**0.474****	**0.383****	**0.560****	**0.489****	**0.534****	**0.305****			
Zn (µg/g FW)			**-0.225***		**-0.283****	**0.607****	**0.719****	**0.633****	**0.465****	**0.430****	**0.533****	**0.449****	**0.563****		
Vit A FW (µg/100g FW)				**0.239****											
Vit C (mg/100g FW)			**-0.213***				**0.218****						**0.284****	**0.282****	**-0.302****

* Significant at 5% level ** Significant at 1% level

As can be seen in **Table 7**, the minerals and trace elements are highly correlated. The same is observed for vitamin A and C. As expected, the protein levels for both years also show a high significant correlation. Total acidity, total soluble solids and pH are also highly significantly correlated. It was interesting to note that the total acidity levels had higher correlation with the mineral and trace elements than the pH. It was also interesting to note that the moisture content was only correlated with the total acidity and none of the other parameters measured.

4. Conclusions

The physical parameters measured were found to vary more across the different land use than the agroecology from which they were sampled. In contrast, the chemical parameters measured were found to vary more across the agroecology than over the land use. The significance of these results is in its implication for practical use. These fruits are consumed by the local community and are sold in local markets. The same groups of people are also known to suffer from Fe and vitamin A deficiency. The fruit of *C. africana* was found to be rich in both Fe and vitamin A, and can be used as a good source for supplementing. Vitamin C is one of the most studied and recommended vitamins, its recommended use ranges from preventing and treating scurvy and cold to preventing and treating cancer as it is a good anti-oxidant. Needless to say consumption of vitamin C by all segments of the population is highly recommended. Therefore, consumption of this fruit should be good for all segments of the population. Therefore we can state that the fruit of *C. africana* is a useful fruit in Ethiopia. Understanding the use of the fruit is important to promote its planting, management, use and marketing in the future.

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Conflicts of Interest

The authors declare no conflict of interest.

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PAPER III

Cordia africana (Lam.) fruit processing in the fresh and dried form

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Abstract

Cordia africana (Lam.) is a small fruit eaten in Tigray, Ethiopia and Africa. The fresh fruits are sold in the market place in open containers and traditionally the fruit is dried on the trees like dates. A more conventional method of processing the fruits was tried. For the fresh fruits, the traditional method of handling collected 7.6 grams dust per kilo of fruit. The TP (total phenol measured with Folin Ciocalteu`s reagent) content varied significantly between the processing methods. For the dried fruits the direct solar direr dried the fruits within 5 days while on-tree drying process took 65 days. The taste of the fruits dried in the direct solar drier was less preferred to that of on-tree dried fruits; however the tastes became similar after the fruits were stored for a year. The TP values were found to be good in the dried fruits with 200 grams of fruit being enough daily. In addition, the vitamin A and vitamin C levels were still good, while the iron content is not expected to change. Therefore, the dried fruits can still be used to partially meet the daily nutritional requirements. For both fresh and dried fruits the organic acid and basic sugar profile did not show a very clear picture, as the difference in rainfall and evaporation rates between the different years interfered. The HSCG gave 20 volatile organic compounds and the HSGCMS gave 39 volatile organic compounds with 12 in common between the two methods.

Keywords: *Cordia africana* fruit*;* fresh and dried fruits, physical and chemical characteristics.

Introduction

The *Cordia africana* fruit is widely eaten in most parts of Ethiopia and other countries in Africa [1-4]. During the study it was found that the fruit is used both fresh and dried. The tree produces lots of fruit during a season in which other fruits are produced only through irrigation and other food stores are running low. The tree is also known to produce fruit in drought years as the tree has deep roots. The fruit was found to be a very good source of total phenol antioxidants. In addition, it is a good partial source for the nutritionally important iron and vitamin A, and of protein, calcium, copper, potassium, magnesium, manganese, prosperous, and vitamin C [5, 6]. Traditionally, the fresh fruit is collected, sorted and cleaned by hand and laid out in plastic pots in the sun before and during selling. This marketing of the fresh fruit is limited to small scale local markets. The dried fruit is mainly consumed at household levels and seldom sold. Fruit drying is an age old method of preservation, with unique traditions and methods all over the world [7]. Traditionally, the fruits are dried on the tree like dates [8, 9]. The process of drying fruits on trees has not been studied in detail except for the study done on dates. Thus the investigation of the actual drying process was found to be important. In addition, it was thought that it may be more nutritious and economical to dry the fruits in box or cabinet direct solar dryers [10, 11]. Thus a comparison of the two processes was undertaken.

The improvement of the marketing of this fruit is important in that it improves the overall nutrition of the Ethiopian population while also improving the income of local producers and processors. To improve the marketing of the fruit and securing food safety, the processing, packaging, and market networking needs improvement [12-20]. To look at the post-harvest processing improvement potential, processing methods that included collection, sorting, washing, air drying under shade, and storage in cleaner open air containers was compared to the traditional processing methods.

Objectives:

The objective of this study was to compare contemporary and traditional *Cordia africana* fresh and dried fruit processing effects as related to time, visual presence of micro-organisms, physical parameters, moisture, vitamin A and C, antioxidant levels and organic acid profiles.

Material and methods

2.1 *Corida africana* fruit sampling strategy

Five *Cordia african* trees were selected and marked. All the processing tests were undertaken on these fruits.

Fresh fruits: Fruits were collected from all five trees, and these were divided into three parts. The first part was frozen immediately. The second part was washed; air dried, and laid out in the shade for seven days to represent what would happen to it if it was sold in shops. After seven days they were frozen. The third part was given to a traditional fruit merchant to process. She washed the fruits; air dried them and laid them out in plastic containers on the floor in the market. The fruits were thus exposed to the sun, wind, dust and handling during the day and were taken into the house overnight for seven days. After seven days they were frozen. All the fresh fruits were frozen until processed for further analysis.

Dried fruits: From each tree, ten bunches were selected. From these ten bunches, the fruit from five bunches were taken to the direct solar dryer and the fruit on the other five were left on the trees. On each of the ten bunches ten fruits were marked out with thread. In the direct solar dryer, each fruit was measured daily, on the tree each fruit was measured every other day. The fruits vertical and diagonal diameters and colour was measured. Each time a measurement was taken; two fruits were taken out to determine the moisture content of the bunch. This process was done in 2010 and 2012.

2.2 Analytical methods

Per tree, the size, colour, weight, moisture and ash were determined from representative individual fruits selected from the fruit bunches, while TP, FRAP, and vitamin A and C, and organic acid profile values were determined from the homogenized samples. For homogenization initially the fruit cap was removed; then the fruit skin was removed. Following this, the sticky flesh was dissolved into a specified amount of water (50-150 ml depending on number of fruits collected and fruit flesh size) by blending it with an egg whisk. When the stone and flesh are separated the skin is placed into the dissolved fruit flesh and blended into a homogenized fruit pulp paste. As the homogenisation process involved dilution, TP, FRAP and vitamin A and C, and organic acid profile values were calculated back to discount the dilution. The principles followed in the analytical measurements were the following:

1. Physical description of the fruits

- Size (cm): the size was measured on both diagonal and vertical directions of the fruit [21]. This was done using a micro-calliper.
- Colour (L*a*b): the colour was initially measured using a colour chart from the Natural Colour Systems [22]. The Natural Colour Systems colours were then converted to the CIE L*a*b* colour [23, 24] reading using a Minolta colour meter.
- Hardness: the hardness was measured using personal judgment and hardness classes of Medium, Soft, and Hard were set.

2. Physico-chemical properties

- Moisture content (%): was determined following the AOAC 934.06 standard [25].
- Vitamin C (mg/100g): was measured following AOAC 967.21 standard with the Metaphosphoric acid–acetic acid solution replaced by 0.1% Oxalic acid [26, 27].
- Vitamin A (µg/100g) was measured using the method where trans-β-carotene was extracted one time with ethanol:hexane (4:3 v/v) and two times with hexane. The determination was carried out by rp-HPLC with UV/DAD detection (450 nm). For quantification a 3-point calibration curve was used. The calibration standards used were pure compounds from Sigma, purity > 98 %. The purity of the standards for each calibration was determined by a series of spectrophotometric measurements (UV 340/455/483 nm) method described in DIN EN 12823-2:2000 [28-30].
- Ferric Reducing Activity Power (FRAP) (µ mol/L): 3 g of the homogenate was extracted in 30 ml of methanol, centrifuged and the supernatant was mixed with acetate buffer, TPTZ and iron trichloride, incubated for 10 minutes and the absorbance was measured at 595 nm. Standards were prepared using Trolox to which readings were compared, following the Konelab 30i outline and method [31, 32].
- Total Phenols (TP) (mg GAE/100 g): 3 g of the homogenate was extracted in 30 ml of methanol, centrifuged and the supernatant was mixed with Folin Ciocalteu`s reagent and 7.5 % (w/v) sodium carbonate, then incubated for 15

minutes, after which it was measured at 765nm. Standards were prepared using Gallic acid to which readings were compared. For the analysis the Konelab 30i outline and method was followed [31, 32].

- Basic sugars and organic acids: for the High Pressure Liquid Chromatography (HPLC) (ppm): 1 gram samples were prepared by mixing it with 2.5 ml of ultra-pure water, 0.2 ml 1N H_2SO_4 and 8.0 ml of acetonitrile (Merck KGaA, Darmstadt, Germany). The mixture was shaken by hand and then by a rotary mixer for 30 minutes. After mixing the sample was centrifuged at ca. 1500 x g for 15 min. The supernatant was then filtered through a filter with 0.2 µl pore size and filled directly into the sample vial and sealed with a plastic cap. Separation of organic acids and carbohydrates was achieved by injection of 25 µl of the filtered sample onto an Aminex HPX-87H HPLC column (Bio-Rad Labs., Richmond, CA, USA), at 32^0C. As the mobile phase, H_2SO_4 (5mM) at a flow rate of 0.4 ml min^{-1} was used. The detection of organic acids and basic sugars was made using a UV detector set at 210 nm and a refractive index detector respectively (Perkin Elmer, Norwalk, CT, USA). Quantification was done through comparisons of retention times against that of standards made of known concentration mixed in ultra-pure water. [33, 34].
- Volatile organic compounds: for the Headspace Gas Chromatography (HSGC) (ppm):10 grams samples weighed into a headspace vial and sealed with a Teflon coated septum and aluminium ring. Samples were equilibrated at 50°C for 45 minutes in a Hewlett Packard HP 7694 headspace sampler and a sample of 1.0 ml headspace gas was injected into the GC using nitrogen as a carrier gas at a flow rate of 5 ml min^{-1}. The headspace manifold was set at 60^0C. Separation of the volatile compounds was achieved using a CP-Sil 5 CB column, 25m, i.d. 0.53 mm and 5 µm film thickness and applying a GC temperature program of: 53^0C 1 min; increase at 15^0C min^{-1} to 70^0C, 2 min; increase at 22^0C min^{-1} to 130^0C, 3 min. External calibration curves with standard solutions were used to identify and quantify the compounds [33].
- Volatile organic compounds: for the Headspace Gas Chromatography Mass Spectrometry (HSGCMS): samples were prepared the same way as the HSGC. Volatiles were sampled dynamically using a Teledyne Tekmar HT3™ Static/Dynamic Headspace System with HT3 Teklink Ver. 1.2.1104 software (Teledyne Tekmar, Mason, OH). Vial conditions were 50˚C with a preheating time of 5 min and mixing set at five. Then a helium flow of 50 ml/min for 10 min was used to trap the volatiles on Tenax® GR 60/80 mesh size (Supelco Analytical, Bellefonte, PA) kept at 25˚C. Dry purge flow was 75 ml/min for 2 min at 25˚C. Desorption was performed at 280˚C with a gas flow of 75 ml/min for 5 min with transfer line temperature of 100˚C. Separation was performed using a 6890N Network GC System (Agilent Technologies, Waldbronn, Germany) fitted with a DB-WAXETR 30 m × 0.25 mm × 0.50 µm capillary column (Agilent Technologies) with 1 ml/min helium as carrier gas. Temperature programme was 30˚C for 10 min, then 1˚C/min to 40˚C, 3˚C/min to 70˚C and 6.5˚C/min to 230˚C followed by 5 min hold-time. Detection was by a 5975 Inert XL Mass Selective Detector (Agilent Technologies) with the following conditions; electron ionization mode (70 eV) with ion source temperature at 200˚C scanning continuously the range 33 to 300 m/z. The GC/MS used MSD ChemStation D.02.00.275 software and the volatile compounds were identified using NIST MS Search 2.0 (Agilent

Technologies), using retention times and with authentic single reference compounds. Performance of the system was verified with blanks and standards [35].

Results

Physical characteristics

Fresh fruits

The fresh fruit once processed was divided in to two groups processed in the modern and traditional forms. At the end of the seventh day both conventionally and traditionally processed fruits showed no visible signs of microbial presence. Though the fruits in both cases were in similar form, the traditionally processed fruits had a lot of dust on and with them. With simple shaking, the dust was removed and per kilogram of fruit there was an average of 7.6 grams of dust. This was not surprising considering they were laid out on dusty streets. The overall physical characteristics measured are presented in Table1.

On the seven day, the processed fruits were significantly different is diagonal size compared to the fresh fruit off the trees. In a similar manner the processed fruits were significantly different in colour from the fruits fresh off the tree, with the colour being darker with less green, less yellow, more red and more blue on the seventh day. The traditionally processed fruits were significantly direr compared to the fresh fruit off the trees, however there was no significant difference between fresh from the tree fruits and the modern processed fruits with respect to the other parameters. All the noted significant changes can be explained by the drying process of the fruit. The fresh fruit off the tree values are consistent with a study looking at more trees in the region [6].

Dried fruits:

The fruits dried in the direct solar dryer grew mould as the weather was unusually moist and the fruits were stored in plastic bags. A second set of drying was undertaken and the fruits were dried further than that of the first trial and were stored in paper bags. The measurement data of both drying trials are presented in Table 2.

As can be seen from the Table below, the number of days the fruits dried to in the second drying was the same and the moisture content was lower as the fruits were collected later in the season. During the second drying the fruit size was smaller, the colour darker with more red/magenta colour in it, and less yellow colour in it. All these differences can be explained by the fact that the fruits used in the second drying were collected later in the fruiting season.

The overall data summary of the fruit drying process on the trees is presented in Table 3 below.

The drying process on the tree took 65 days with 33 days measurement. The average values presented above only give the overall picture; the changes that occurred through time can be seen in the minimum and maximum values. They are however better represented in the time series analysis, shown in the following box plot of the moisture content in Figure 1, Figure 2 and Table 4. The prolonged time it takes the fruits to dry on the trees leaves them exposed to bird and insect attack, incidental rain causing fungal and other microbial growth, thus considering the physical parameters only, the direct solar dryer gave better dried fruits.

The time series data was collected over 5 and 65 days spans. The information of the basic parameters measured is thus summarised and compared in Table 4.

As can be seen from Table 4 the drying process on the tree took 13 times longer, exposing the fruits to rain, dust, and insect and bird attack. The overall physical parameters were similar. However a simple sensory test undertaken involving 15 people, lab attendants and students showed that the fruits dried on the trees had preferable taste on the third month after the drying process had started. When the same test was undertaken a year after the drying process was started fruits dried in both forms had similar tastes. For this reason further analysis on the aroma compounds and basic sugar profile was undertaken to describe this difference.

Chemical characteristics

Both the dried and fresh fruits were collected, processed and analysed. The ferric reducing ability, total phenol, vitamin C and vitamin A amounts were measured. The summarised result of these measurements and the comparison of means on dry matter basis is presented in Table 5. The dry matter mean was compared to give a similar basis for comparison as the fruits are both fresh and dry.

From the results it can be noted that the fresh fruit processing did not show any significant difference with respect to the FRAP and vitamins tested, while it varied significantly for the total phenol values. Looking at the dried fruits, the same pattern can be seen for the vitamins, while the FRAP and TP values varied significantly. Both the results show that the TP and FRAP varied significantly across the different processing methods used. The results are however offset by the fact that 2010 was an exceptionally wet year, while 2012 was a relatively drier one. The monthly rainfall for April and May was 79.4 and 29.9 in 2010 and 37 and 20.6 mm per month in 2012 respectively. During the same time the average daily evaporation rate was 9.6 and 9.18 in 2010 and 9.12 and 10.18 mm per day in 2012. This gave an average deficit of 227.05 mm per month for 2010 and 260.7 mm per month for 2012. This can be seen in the fact that the fruits stored for two years had more antioxidants in the TP and FRAP measurement than the freshly dried fruits. As would be expected per dry matter comparison the fresh fruits had significantly higher vitamin C and vitamin A levels [26, 36]. However, the dried fruits still had a good content of vitamin C even after two years of storage; consumption of just 967 grams would meet the daily intake requirement [37]. The vitamin A tough further reduced can still be used as a partial source, and a kilo of fruit will be needed to meet the daily intake requirement. The TP values were also good in that eating 200 grams or more fruit would meet the American and European dietary standards [38, 39].

The tastes of the processed fruits were compared, by a simple untrained panel and using organic acid and basic sugar profiling. The panellists found the taste of the on-tree dried fruits to be preferable in the short term; however this difference was not noticeable after a year of storage. For this reason a comparison was undertaken using basic sugars, organic acids and volatile organic compounds using HPLC, HSGC and HSGCMS. The results of this are briefly presented in Table 6, and extensively presented in Table 7 and Table 8 in the appendix.

In the HPLC maltose, glucose, fructose, citric acid, succinic acid and acetic acid were identified and their quantities were measured. In the HSGC 17 volatile organic compounds were identified and their quantities were measured. The details of which are presented in Table 7 in the appendix. Comparing the dried and fresh fruits, only five compounds 3-metyl-1-butanol, acetoin, 2-metyl-butanal, 2-metyl-propanal and acetaldehyde were significantly different in concentration as compared to the dried fruits. In addition, 2-butanone and 2-butanol are found only in the fresh fruits. The comparison of the dried fruits is again offset by the rainfall difference between the years. Looking at the basic sugars, it is interesting to note that the sugar level in the on-tree dried fruit is consistently as high as that of the fresh fruit for the sample of 2010 for fructose and glucose. In contrast for maltose it is the conventionally dried fruit that resemble the fresh fruits. The ethanol content in all forms of the fruits was consistently very high, though it varied significantly with almost all the processing methods. With the HSGCMS only identification of volatile organic compounds was undertaken, and 39 compounds were identified, and the results are presented in Table 8 in the appendix. The HSGCMS identified compounds were checked in literature and pentane, 2-bromo and dextroamphetamine were not found in literature on fruits. Paired t-test, one way ANOVA, and cluster analysis tests undertaken on significance of the presence and absence of the compounds showed no significant difference. 21 compounds of the 39 compounds were found in only one of the fruit categories. 12 of the compounds are in common with the HSGC analysis, while 27 were only identified with the HSGCMS method and 8 were identified only in the HSGC method.

Conclusion

The research results showed that the fresh fruit processing and marketing process needs to be improved as the fruits processed in the traditional method found to contain dust, though the vitamin C and A levels did not change significantly from that of the fresh and conventionally processed fruits. The drying process using the direct solar dryer saved a lot of time and keeps the fruits clean and safe from insect and bird attack. However the taste of the fruit was not the same until it was stored for a whole year. Acceptability and cost factors need to be studied and considered for the promotion of the direct solar dryer. The processing method did not have any significant effect on the TP, vitamin C and A levels of the dried fruits. Even though the drying process reduced the TP and vitamin C levels, the content was still high enough for the dried fruits to be considered as good sources. The FRAP and TP value comparisons were offset by the difference in rainfall in the two years where sampling was undertaken. The basic sugar, organic acid and volatile organic compound comparisons showed that the fresh and dried fruits varied significantly from each other. Looking at the dried fruits, the difference again was offset by the rainfall variation in the years considered. The HSGC and HSGCMS gave 12 similar compounds. In conclusion, the fresh fruit processing and marketing process needs improvement. The dried fruits were found to still be nutritious, thus drying is a very good method for processing and preserving the fruits. The direct solar dryer saved time and kept the fruits in a better condition, however the taste needed time to mature and this needs further study before promotion.

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Appendix:

This appendix contains the full list of the volatile organic compounds identified through the HPLC, HSGC and HSGCMS analysis.

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Tables and Figures

Table 1, basic physical characteristics of the fresh fruits just after collection and seven days after processing in the modern and traditional forms

Processing method	Statistical variables	D1 (cm)	D2 (cm)	AD (cm)	L*	a*	b*	Hardness	M%
Day 1 fresh fruit (FF)	**Mean**	1.18	1.18	1.18	41.50	-1.63	44.06	M	57.87
	SE Mean	0.02	0.02	0.02	0.77	1.18	0.54	M	1.38
	Minimum	1.13	1.14	1.13	39.78	-4.26	42.64	M	53.49
	Median	1.17	1.15	1.16	41.29	-2.12	44.21	M	58.18
	Maximum	1.25	1.27	1.26	43.81	2.03	45.61	M	61.90
Day 7 traditional processing (FT)	**Mean**	1.07	1.27	1.17	33.51	9.27	37.05	M	49.65
	SE Mean	0.03	0.01	0.02	1.50	0.78	2.27	M	2.15
	Minimum	0.98	1.25	1.11	29.64	6.39	31.29	M	42.78
	Median	1.08	1.26	1.17	34.74	9.65	39.07	M	50.02
	Maximum	1.14	1.32	1.22	36.70	10.83	42.03	M	55.97
Day 7 conventional processing (FM)	**Mean**	1.19	1.33	1.26	32.29	8.46	35.82	M	55.02
	SE Mean	0.04	0.03	0.03	1.17	0.50	1.82	M	1.35
	Minimum	1.11	1.26	1.18	28.93	6.94	30.53	M	51.88
	Median	1.13	1.33	1.23	32.12	8.79	35.38	M	55.25
	Maximum	1.31	1.40	1.35	35.34	9.93	40.50	M	57.98
ANOVA and significance Tukey's grouping			**FF A FM B FT B		**FF A FM B FT B	**FF A FM B FT	*FF A FM B FT B		*FF A FM B FT B

* 5% level of significance and ** 1% level of significance

Table 2 basic summary of the measured parameters in the direct solar drying process

Variable	N days	Mean	SE Mean	Minimum	Median	Maximum
D1 (cm) 1st	5	1.14	0.02	0.80	1.13	1.59
D2 (cm) 1st	5	1.23	0.01	0.94	1.24	1.54
AD (cm) 1st	5	1.19	0.01	0.89	1.16	1.56
L* 1st	5	25.91	0.97	13.06	24.31	47.90
a* 1st	5	3.31	0.32	-5.96	3.52	14.27
b* 1st	5	22.20	1.51	1.35	20.17	53.85
Hardness 1st	5	Soft			Soft	
M% 1st	5	49.90	0.67	31.66	50.42	66.94
D1 (cm) 2nd	5	1.06	0.01	0.85	1.06	1.41
D2 (cm) 2nd	5	1.24	0.01	1.07	1.25	1.45
AD (cm) 2nd	5	1.15	0.01	0. 96	1.14	1.43
L* 2nd	5	24.30	0.81	12.89	19.03	44.29
a* 2nd	5	7.21	0.17	2.25	7.39	11.85
b* 2nd	5	21.39	1.41	0.82	12.16	53.34
Hardness 2nd	5	Soft			Soft	
M% 2nd	5	44.04	1.08	11.66	45.06	64.59

Table 3 basic summary of the measured parameters in the tree drying process

Variable	N days	Mean	SE Mean	Minimum	Median	Maximum
D1 (cm)	65	1.13	0	0.85	1.13	1.38
D2 (cm)	65	1.29	0	1.03	1.29	1.50
AD (cm)	65	1.21	0	0.99	1.20	1.42
L*	65	30.94	0.28	13.51	30.60	74.09
a*	65	8.73	0.16	-11.48	9.78	16.30
b*	65	32.81	0.41	1.66	33.58	82.17
Hardness	65	Soft			Medium	
M%	65	51.56	0.32	16.30	53.25	69.51

Table 4. Time series basic summary of the measured parameters in the dryer and tree drying process

Variable	Drying method	Day	Mean
Diagonal diameter cm	Dryer	1	1.20
	Tree	**1**	**1.18**
	Dryer	5	1.01
	Tree	**63**	**0.98**
Vertical diameter cm	Dryer	1	1.25
	Tree	**1**	**1.17**
	Dryer	5	1.22
	Tree	**63**	**1.24**
Average diameter cm	Dryer	1	1.23
	Tree	**1**	**1.18**
	Dryer	5	1.12
	Tree	**63**	**1.11**
L*	Dryer	1	36.06
	Tree	**1**	**41.50**
	Dryer	5	16.74
	Tree	**63**	**23.67**
a*	Dryer	1	3.85
	Tree	**1**	**-1.63**
	Dryer	5	5.47
	Tree	**63**	**9.77**
b*	Dryer	1	39.56
	Tree	**1**	**44.06**
	Dryer	5	7.86
	Tree	**63**	**20.77**
Hardness	Dryer	1	Medium
	Tree	**1**	**Medium**
	Dryer	5	Hard & dry
	Tree	**63**	**Hard & dry**
Moisture %	Dryer	1	56.70
	Tree	**1**	**57.87**
	Dryer	5	40.40
	Tree	**63**	**46.82**

Table 5. The total phenol, ferric reducing antioxidant power, vitamin C and vitamin A values of fresh and dried processed fruits of *Cordia africana* with a one way ANNOVA comparison of means, fresh (FW) and dry weight (DM) basis

Component analysed	Fruit treatment	Mean DW	Mean FW	Tukey's grouping DW	P	Sign.
Total Phenol value in (mg GAE/100 g FW)	Fresh fruit	69.16±0.13	31.32±0.82	A	0.000	*
	Fresh fruit treated conventional	60.57±1.21	30.61±0.69	B		
	Fresh fruit treated traditional	52.60±1.13	30.35±0.48	C		
	2012 dried fruit conventional	33.44±0.30	32.07±0.27	D		
	2012 dried fruit traditional	31.22±1.06	29.68±0.97	D		
	2010 dried fruit conventional	57.35±1.91	53.09±0.85	BC		
	2010 dried fruit traditional	60.74±1.59	53.93±1.25	B		
FRAP value in (µ mol/L)	Fresh fruit	55.94±1.45	24.32±0.93	B	0.000	*
	Fresh fruit treated conventional	58.86±0.14	27.71±1.46	B		
	Fresh fruit treated traditional	58.60±1.65	28.59±0.84	B		
	2012 dried fruit conventional	30.49±0.67	29.24±0.67	C		
	2012 dried fruit traditional	31.12±0.04	29.71±0.06	C		
	2010 dried fruit conventional	58.05±0.20	54.45±0.81	B		
	2010 dried fruit traditional	68.27±0.85	60.54±0.82	A		
Vitamin C(mg/100g)	Fresh fruit	21.87±2.14	7.65±0.31	A	0.000	*
	Fresh fruit treated conventional	16.86±0.554	6.87±0.29	A		
	Fresh fruit treated traditional	18.82±0.752	6.77±0.23	A		
	2012 dried fruit conventional	8.04±0.90	7.86±0.77	B		
	2012 dried fruit traditional	6.52±1.15	6.58±1.26	B		
	2010 dried fruit conventional	7.31±0.79	6.84±0.86	B		
	2010 dried fruit traditional	6.21±0.78	5.51±0.68	B		
Vitamin A (µg/100g)	Fresh fruit	1768.0±142.0	212.0±28.8	A	0.000	*
	Fresh fruit treated conventional	2713.0±490.0	229.3±34.9	A		
	Fresh fruit treated traditional	2651.0±496.0	237.8±45.3	A		
	2012 dried fruit conventional	304.6±37.6	49.7±7.9	B		
	2012 dried fruit traditional	279.6±30.7	48.0±5.2	B		
	2010 dried fruit conventional	518.6±94.3	61.2±10.2	B		
	2010 dried fruit traditional	372.4±73.4	42.2±8.4	B		

* Significant at 1%

Table 6. HPLC, HSGC organic acid, basic sugar and volatile organic compounds profile of fresh and dried processed fruits of *Cordia africana* with a one way ANOVA comparison of means

Component analyzed		Fruit treatment	Mean DW	Mean FW	Tukey's grouping DW	P	Sign.
Sugars HPLC (ppm)	Maltose	Fresh fruit	170864±15475	94335±10405	B	0.000	**
		Fresh fruit treated conventional	334783±61797	156397±29756	A		
		Fresh fruit treated traditional	407231±42674	155100±14618	A		
		2012 dried fruit conventional	87017±2537	8560±383	C		
		2012 dried fruit traditional	66478±24424	8043±3187	C		
		2010 dried fruit conventional	179555±29545	19111±3619	B		
		2010 dried fruit traditional	62874±15716	8373±2174	C		
	Glucose	Fresh fruit	85496±17537	46567±8543	C	0.000	**
		Fresh fruit treated conventional	169294±34021	79391±17120	AB		
		Fresh fruit treated traditional	114380±21280	43637±8136	BC		
		2012 dried fruit conventional	47267±10772	4510±759	C		
		2012 dried fruit traditional	70952±5930	8312±745	C		
		2010 dried fruit conventional	80700±9868	8685±1809	C		
		2010 dried fruit traditional	229570±13234	30997±2764	A		
Organic acid HPLC (ppm)	Citric acid	Fresh fruit	21335±2490	11822±1710	B	0.000	**
		Fresh fruit treated conventional	49181±4426	22867±2117	A		
		Fresh fruit treated traditional	47336±7365	18022±2784	A		
		2012 dried fruit conventional	7959±2043	783±196	C		
		2012 dried fruit traditional	7792±879	911±100	C		
		2010 dried fruit conventional	21826±2277	2313±355	B		
		2010 dried fruit traditional	23324±2170	3127±306	B		
	Acetic acid	Fresh fruit	22846±6743	12551±3901	AB	0.023	*
		Fresh fruit treated conventional	38675±13175	17878±6026	AB		
		Fresh fruit treated traditional	38727±11274	15017±4322	AB		
		2012 dried fruit conventional	11145±2853	1073±263	C		
		2012 dried fruit traditional	19698±6031	2372±814	BC		
		2010 dried fruit conventional	42204±7947	4582±1081	AB		
		2010 dried fruit traditional	51345±6024	6900±909	A		
Volatile organic compounds HSGC (ppm)	Acetaldehyde	Fresh fruit	178.9±18.1	99.1±12.6	A	0.000	**
		Fresh fruit treated conventional	206.4±16.5	96.20±8.83	A		
		Fresh fruit treated traditional	165.8±16.1	63.68±6.95	A		
		2012 dried fruit conventional	14.43±1.52	1.422±0.175	B		
		2012 dried fruit traditional	28.07±3.26	3.302±0.437	B		
		2010 dried fruit conventional	24.43±4.08	2.637±0.583	B		
		2010 dried fruit traditional	26.40±4.55	3.483±0.539	B		
	Diacetyl	Fresh fruit	2.250±0.885	1.273±0.533	B	0.002	**
		Fresh fruit treated conventional	3.696±0.700	1.705±0.295	AB		
		Fresh fruit treated traditional	7.24±2.59	2.80±1.07	A		
		2012 dried fruit conventional	2.773±0.214	0.2749±0.0307	AB		
		2012 dried fruit traditional	0.931±0.336	0.1097±0.0394	B		
		2010 dried fruit conventional	1.007±0.346	0.1063±0.0367	B		
		2010 dried fruit traditional	0.659±0.314	0.0883±0.0429	B		

* Significant at 5%   ** Significant at 1%

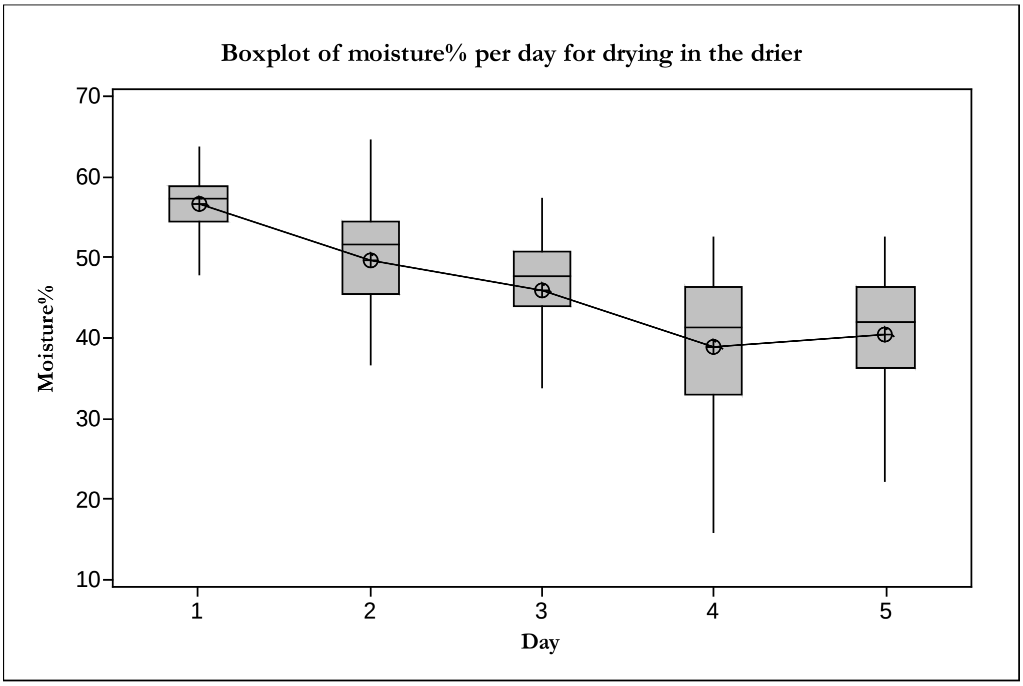

Figure 1. Time series showing box plot value of moisture content of fruits per days

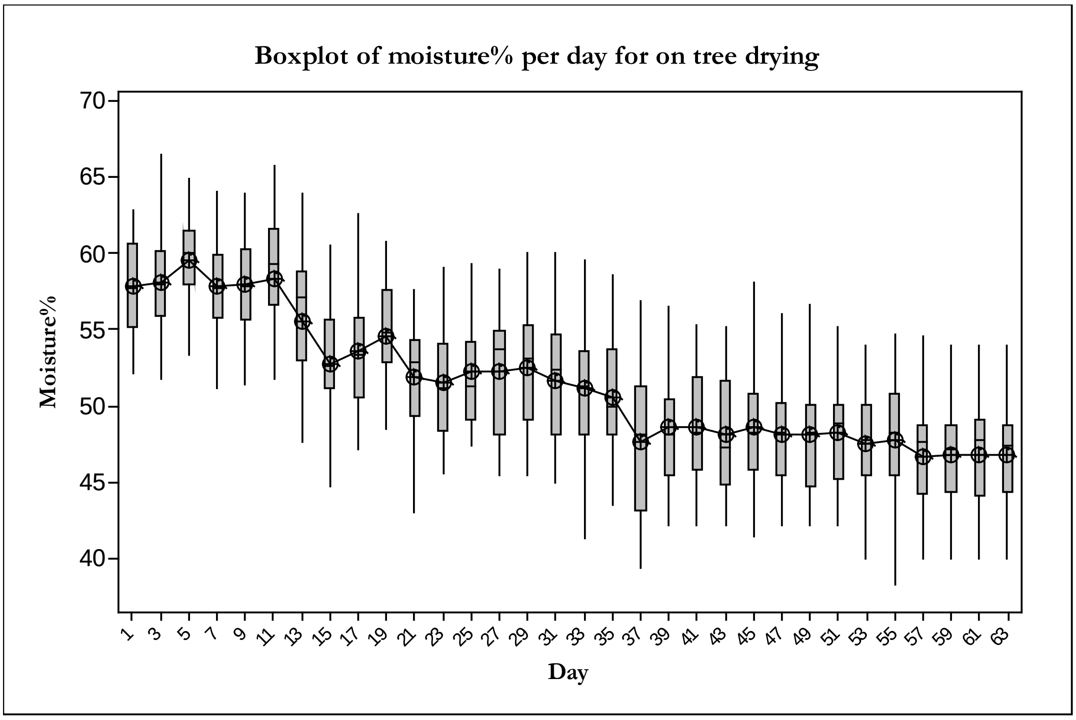

Figure 2. Time series showing box plot value of moisture content of fruits per days

Appendix:

This appendix contains the full list of the volatile organic compounds identified through the HPLC, HSGC and HSGCMS analysis.

Table 7, The HPLC, HSGC organic acid, basic sugar and volatile organic compounds profile of fresh and dried processed fruits of *Cordia africana* with a one way ANOVA comparison of means

Component analyzed		Fruit treatment	Mean DW	Mean FW	Tukey's grouping DW	P	Sign.
Sugars HPLC (ppm)	Maltose	Fresh fruit	170864±15475	94335±10405	B	0.000	**
		Fresh fruit treated conventional	334783±61797	156397±29756	A		
		Fresh fruit treated traditional	407231±42674	155100±14618	A		
		2012 dried fruit conventional	87017±2537	8560±383	C		
		2012 dried fruit traditional	66478±24424	8043±3187	C		
		2010 dried fruit conventional	179555±29545	19111±3619	B		
		2010 dried fruit traditional	62874±15716	8373±2174	C		
	Glucose	Fresh fruit	85496±17537	46567±8543	C	0.000	**
		Fresh fruit treated conventional	169294±34021	79391±17120	AB		
		Fresh fruit treated traditional	114380±21280	43637±8136	BC		
		2012 dried fruit conventional	47267±10772	4510±759	C		
		2012 dried fruit traditional	70952±5930	8312±745	C		
		2010 dried fruit conventional	80700±9868	8685±1809	C		
		2010 dried fruit traditional	229570±13234	30997±2764	A		
	Fructose	Fresh fruit	131242±22720	71954±11839	BC	0.000	**
		Fresh fruit treated conventional	241071±48077	113035±24233	AB		
		Fresh fruit treated traditional	169569±26340	64984±10756	ABC		
		2012 dried fruit conventional	66960±10080	6441±583	C		
		2012 dried fruit traditional	82112±8699	9608±1011	C		
		2010 dried fruit conventional	126250±20901	13713±3314	C		
		2010 dried fruit traditional	253211±13403	34081±2621	A		
Organic acid HPLC (ppm)	Citric acid	Fresh fruit	21335±2490	11822±1710	B	0.000	**
		Fresh fruit treated conventional	49181±4426	22867±2117	A		
		Fresh fruit treated traditional	47336±7365	18022±2784	A		
		2012 dried fruit conventional	7959±2043	783±196	C		
		2012 dried fruit traditional	7792±879	911±100	C		
		2010 dried fruit conventional	21826±2277	2313±355	B		
		2010 dried fruit traditional	23324±2170	3127±306	B		
	Succinic acid	Fresh fruit	13501±3036	7379±1579	B	0.000	**
		Fresh fruit treated conventional	28904±4202	13393±1875	B		
		Fresh fruit treated traditional	62238±12142	23431±4211	A		
		2012 dried fruit conventional	9615±1341	945±131	C		
		2012 dried fruit traditional	8371±1000	974.3±99.5	C		
		2010 dried fruit conventional	26943±3467	2890±544	B		
		2010 dried fruit traditional	23154±1396	3118±267	B		
	Acetic acid	Fresh fruit	22846±6743	12551±3901	AB	0.023	*
		Fresh fruit treated conventional	38675±13175	17878±6026	AB		
		Fresh fruit treated traditional	38727±11274	15017±4322	AB		
		2012 dried fruit conventional	11145±2853	1073±263	C		
		2012 dried fruit traditional	19698±6031	2372±814	BC		
		2010 dried fruit conventional	42204±7947	4582±1081	AB		
		2010 dried fruit traditional	51345±6024	6900±909	A		
Volatile organic	Acetaldehyde	Fresh fruit	178.9±18.1	99.1±12.6	A	0.000	**
		Fresh fruit treated conventional	206.4±16.5	96.20±8.83	A		
		Fresh fruit treated traditional	165.8±16.1	63.68±6.95	A		
		2012 dried fruit conventional	14.43±1.52	1.422±0.175	B		
		2012 dried fruit traditional	28.07±3.26	3.302±0.437	B		
		2010 dried fruit conventional	24.43±4.08	2.637±0.583	B		

		2010 dried fruit traditional	26.40±4.55	3.483±0.539	B		
	Ethanol	Fresh fruit	6272±341	3450±236	A	0.000	**
		Fresh fruit treated conventional	3607±345	1680±175	B		
		Fresh fruit treated traditional	1627±330	631±145	C		
		2012 dried fruit conventional	211.2±20.5	20.60±1.67	D		
		2012 dried fruit traditional	75.6±16.3	8.77±1.69	E		
		2010 dried fruit conventional	20.63±6.47	2.188±0.701	F		
		2010 dried fruit traditional	30.60±3.00	4.087±0.384	EF		
	Aceton/ Acrolein	Fresh fruit	5.33±2.45	2.94±1.38	A	0.025	*
		Fresh fruit treated conventional	0.726±0.190	0.3343±0.0842	BC		
		Fresh fruit treated traditional	0.836±0.085	0.3225±0.0417	B		
		2012 dried fruit conventional	0.772±0.193	0.0739±0.0178	BC		
		2012 dried fruit traditional	0.328±0.089	0.0395±0.0126	C		
		2010 dried fruit conventional	0.661±0.065	0.0700±0.0105	BC		
		2010 dried fruit traditional	0.834±0.065	0.1121±0.0106	B		
	2-metyl-propanal	Fresh fruit	1.810±0.412	1.009±0.252	A	0.000	**
		Fresh fruit treated conventional	1.953±0.412	0.912±0.198	A		
		Fresh fruit treated traditional	2.589±0.423	0.986±0.151	A		
		2012 dried fruit conventional	0.2782±0.0229	0.0277±0.0036	B		
		2012 dried fruit traditional	0.1891±0.0354	0.0221±0.0040	B		
		2010 dried fruit conventional	0.2660±0.0390	0.0275±0.0041	B		
		2010 dried fruit traditional	0.1774±0.0288	0.0234±0.0032	B		
	Diacetyl	Fresh fruit	2.250±0.885	1.273±0.533	B	0.002	**
		Fresh fruit treated conventional	3.696±0.700	1.705±0.295	AB		
		Fresh fruit treated traditional	7.24±2.59	2.80±1.07	A		
		2012 dried fruit conventional	2.773±0.214	0.2749±0.0307	AB		
		2012 dried fruit traditional	0.931±0.336	0.1097±0.0394	B		
		2010 dried fruit conventional	1.007±0.346	0.1063±0.0367	B		
		2010 dried fruit traditional	0.659±0.314	0.0883±0.0429	B		
	2-butanone	Fresh fruit	0.0484±0.0484	0.028±0.028	B	0.000	**
		Fresh fruit treated conventional	0.3069±0.0745	0.144±0.036	A		
		Fresh fruit treated traditional	0.2826±0.0978	0.107±0.039	A		
		2012 dried fruit conventional	0.000±0.000	0.000±0.000	B		
		2012 dried fruit traditional	0.000±0.000	0.000±0.000	B		
		2010 dried fruit conventional	0.000±0.000	0.000±0.000	B		
		2010 dried fruit traditional	0.000±0.000	0.000±0.000	B		
	2-butanol	Fresh fruit	0.000±0.000	0.000±0.000	B	0.000	**
		Fresh fruit treated conventional	0.2203±0.079	0.104±0.037	A		
		Fresh fruit treated traditional	0.257±0.101	0.096±0.037	A		
		2012 dried fruit conventional	0.000±0.000	0.000±0.000	B		
		2012 dried fruit traditional	0.000±0.000	0.000±0.000	B		
		2010 dried fruit conventional	0.000±0.000	0.000±0.000	B		
		2010 dried fruit traditional	0.000±0.000	0.000±0.000	B		
	Ethyl acetate	Fresh fruit	1.019±0.158	0.5595±0.0878	A	0.000	**
		Fresh fruit treated conventional	0.5397±0.0678	0.2506±0.0309	BC		
		Fresh fruit treated traditional	0.2508±0.0670	0.0946±0.0239	CD		
		2012 dried fruit conventional	0.6704±0.0323	0.0661±0.0043	B		
		2012 dried fruit traditional	0.1158±0.0586	0.0142±0.0076	D		
		2010 dried fruit conventional	0.0524±0.0214	0.0060±0.0025	D		
		2010 dried fruit traditional	0.1242±0.0224	0.0167±0.0032	D		
	2-m et	Fresh fruit	1.181±0.131	0.6450±0.0651	AB	0.002	**
		Fresh fruit treated conventional	1.226±0.303	0.571±0.144	AB		

		Fresh fruit treated traditional	2.552±0.577	0.993±0.258	A		
		2012 dried fruit conventional	0.2517±0.0466	0.0254±0.0053	B		
		2012 dried fruit traditional	0.3856±0.0687	0.0443±0.0066	B		
		2010 dried fruit conventional	0.000±0.000	0.000±0.000	B		
		2010 dried fruit traditional	0.925±0.660	0.1285±0.0942	AB		
	3-metyl-butanal	Fresh fruit	1.739±0.608	0.977±0.359	A	0.000	**
		Fresh fruit treated conventional	1.449±0.382	0.675±0.180	AB		
		Fresh fruit treated traditional	1.802±0.375	0.686±0.137	A		
		2012 dried fruit conventional	0.5145±0.0424	0.05117±0.00596	ABC		
		2012 dried fruit traditional	0.1408±0.0330	0.01667±0.00405	BC		
		2010 dried fruit conventional	0.2915±0.0526	0.03033±0.00579	BC		
		2010 dried fruit traditional	0.1595±0.0184	0.02128±0.00247	C		
	2-metyl-butanal	Fresh fruit	3.297±0.815	1.828±0.486	A	0.000	**
		Fresh fruit treated conventional	3.222±0.699	1.506±0.337	A		
		Fresh fruit treated traditional	3.707±0.378	1.420±0.147	A		
		2012 dried fruit conventional	0.4877±0.0481	0.04832±0.00647	B		
		2012 dried fruit traditional	0.375±0.105	0.0438±0.0120	B		
		2010 dried fruit conventional	0.4436±0.0636	0.04522±0.00586	B		
		2010 dried fruit traditional	0.3378±0.0611	0.04459±0.00703	B		
	2.3-pentadione	Fresh fruit	1.943±0.721	1.031±0.355	AB	0.001	**
		Fresh fruit treated conventional	2.528±0.856	1.179±0.401	A		
		Fresh fruit treated traditional	0.779±0.167	0.2977±0.0632	ABC		
		2012 dried fruit conventional	0.192±0.123	0.0176±0.0107	BC		
		2012 dried fruit traditional	0.410±0.151	0.0477±0.0171	BC		
		2010 dried fruit conventional	0.0839±0.0548	0.0085±0.0057	C		
		2010 dried fruit traditional	0.217±0.103	0.0283±0.0137	BC		
	Acetoin	Fresh fruit	167.23±7.97	92.28±7.21	A	0.000	**
		Fresh fruit treated conventional	142.6±20.7	66.6±10.5	A		
		Fresh fruit treated traditional	164.3±10.0	62.58±2.16	A		
		2012 dried fruit conventional	33.45±3.95	3.304±0.436	B		
		2012 dried fruit traditional	8.07±2.78	0.944±0.317	C		
		2010 dried fruit conventional	10.87±4.10	1.172±0.437	C		
		2010 dried fruit traditional	7.03±2.83	0.894±0.346	C		
	3-metyl-1-butanol	Fresh fruit	3.022±0.682	1.680±0.410	B	0.000	**
		Fresh fruit treated conventional	3.078±0.500	1.439±0.255	B		
		Fresh fruit treated traditional	5.831±0.719	2.222±0.254	A		
		2012 dried fruit conventional	0.5198±0.0943	0.0499±0.0062	C		
		2012 dried fruit traditional	0.377±0.132	0.0424±0.0147	C		
		2010 dried fruit conventional	0.243±0.119	0.0266±0.0132	C		
		2010 dried fruit traditional	0.107±0.107	0.0126±0.0126	C		
	2-metyl-1-butanol	Fresh fruit	2.447±0.694	1.327±0.351	BC	0.000	**
		Fresh fruit treated conventional	3.027±0.762	1.421±0.381	AB		
		Fresh fruit treated traditional	5.38±1.34	2.087±0.587	A		
		2012 dried fruit conventional	0.2841±0.0639	0.02754±0.00519	BC		
		2012 dried fruit traditional	0.658±0.165	0.0756±0.0172	BC		
		2010 dried fruit conventional	0.3531±0.0774	0.03697±0.00835	C		
		2010 dried fruit traditional	0.7080±0.0435	0.09527±0.00784	BC		
	Hexanal	Fresh fruit	0.2625±0.0478	0.1453±0.0274	A	0.000	**
		Fresh fruit treated conventional	0.3116±0.0325	0.1447±0.0150	A		
		Fresh fruit treated traditional	0.1031±0.0134	0.03960±0.00584	B		

		2012 dried fruit conventional	0.0435±0.0106	0.00435±0.00105	B		
		2012 dried fruit traditional	0.0247±0.0034	0.00292±0.00049	B		
		2010 dried fruit conventional	0.0475±0.0086	0.00506±0.00105	B		
		2010 dried fruit traditional	0.0374±0.0063	0.00504±0.00095	B		

Table 8, The frequency distribution of the HSGCMS volatile organic compound profile of fresh and dried processed fruits of *Cordia africana;* fresh fruit (FF), fresh fruit conventionally treated on day 7 (FM), fresh fruit traditionally treated on day 7 (FT), 2012 dried fruit conventional (NDM), 2012 dried fruit traditional (NDT), 2010 dried fruit conventional (ODM), 2010 dried fruit traditional (ODT)

	Fruit treatment code						
Aroma compound	**FF**	**FM**	**FT**	**NDM**	**NDT**	**ODM**	**ODT**
1. Amine (2-Aziridinylethyl)	3	3	3				
2. 1.3 – Butane diamine							1
3. 1-Butanol, 2-methyl	2	2	4		4	1	3
4. 1-Butanol, 3-methyl	2	2		3			1
5. 1-Hexanol, 2-ethyl							1
6. 1-Pentanol, 2-amino	2						
7. 1-Pentanol, 4-amino					1	2	1
8. 1-Propanol, 2-amino							1
9. 1-Propanol, 2-methyl		3	2				
10. 1-Propanol, 4-amino							1
11. 2,3-Butanedione				1			
12. 2-Butanone, 3-hydroxy	4	1	4	1	3		
13. 2-Propenal	2						
14. 3-Furaldehyde							1
15. 3- Pyridinecarboxaldehyde, O-acetyloxime, (E)						1	
16. Acetaldehyde	4	4	4	4	5	5	6
17. Acetic acid	2	4	3	3	2	3	5
18. Acetone				1			
19. Ammonium Oxalate					1		
20. Butanal							1
21. Butanal, 2-methyl	2	1	1	3	2	3	5
22. Butanal, 3-methyl	1	1		3	1	5	5
23. Cyclobutanol				1			
24. Cyclohexanone, 3-hydroxy	1						
25. Dextroamphetamine *					1	1	
26. Ethyl acetate	4	4	4	4	3		2
27. Ethylalchohol	4	4	4	3	3		
28. Ethylhydrogen oxialate	4	1					
29. Ethyne, fluoro				1	2	3	5
30. Hexanal		1					
31. Hydroperoxide, hexyl	3	3	3		1		
32. O-Methylisourea hydrogensulfate		1			2		
33. Oxirane, (1-methylbutyl)					2		
34. Oxirane, 2,2 – dimethylpropyl							1
35. Pentanal						1	
36. Pentane, 2-bromo *	1						
37. Phenol							1
38. Propanal, 2-methyl	2	3	2	4	3	5	4
39. Styrene			2				

* compounds not found in literature on fruits

PAPER IV

Traditional medicinal use of *Cordia africana* (Lam.) fruits

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Abstract

Traditional medicine is an important part of people's life in Ethiopia as it is in many other developing countries. Ethiopia has a rich resource of medicinal plants used traditionally. *Cordia africana* (Lam.) is a medicinal fruit tree that grows all over Tigray, other parts of Ethiopia and Africa. Its leaves, bark, stem and root have been shown to have medicinal properties, while the fruit has not been studied. This study focuses on the traditional medicinal use of the fruit from *C. africana*. A key informant survey undertaken on the medicinal use of the fruit showed that it was predominantly used to treat gastro-intestinal ailments. Helminths were mentioned as one of the causes of these illnesses, and the fruit of *C. dichotoma* is known to have anthelmintic properties. The fruit of *C. africana* coming from the same genera probably has similar properties; and the fruit has been used as a food source for centuries with no side effects, therefore shows great potential for further study. In the Ethiopian setting and the overall de-worming campaigns, it is believed the results of such a study will be useful.

Keywords: *Cordia africana* fruit; traditional medicinal use

Short title: Traditional medicinal use of *Cordia africana* fruit

Abbreviations and/or nomenclature

m.a.s.l.: meters above sea level
ml: mille litters

Introduction

The population in Ethiopia as many other developing countries relies on traditional knowledge for treatment of illnesses, and this has resulted in the accumulation and retention of valuable information on these plants (Abbink 1995; Abebe 2001; Balemie et al. 2004; Birhane et al. 2011; Edwards & Asfaw 1992; Gedif & Hahn 2003; Hailemariam et al. 2009; Hunde et al. 2004; Zenebe et al. 2012). Ethiopia has a unique environment with a long culture of crop domestication and plant exploitation which has lead to the development of both domestic and wild plants of great diversity (Abebe 2001; Asfaw & Tadesse 2001; Edwards 1989; Edwards 1991; Harlan 1969; Tewolde Berhan Gebre Egziabher 1991). Within the Ethiopian flora there are around 6000 species, from these 126 species in 53 angiosperm families known to contain medicinal properties(Poncet et al. 2009).

Cordia africana (Lam.) is one of the traditionally used medicinal plants of Ethiopia (Geyid et al. 2005; Yirga 2010). It is a tree of the family Boraginacea (Legesse Negash 1995), that produces edible fruits. Synonyms for it are *C. abyssinica* R. Br. ex A. Rich.; *C. holstii* Gürke. (ICRAF 2008); *C. ubanghensis* A. Chev.; *C. sebestena*, *Varronia abyssinica*, *Calyptracordia abyssinica* (FAO 2007). Its natural distribution ranges from Saudi Arabia, Yemen, Angola, Ghana, Guinea, Democratic Republic of Congo, Sudan, Eritrea, Ethiopia, Djibouti, Kenya, Tanzania, Uganda, Zimbabwe, Malawi, Mozambique, to South Africa. It is a good agroforestry species, as it responds well to pollarding, lopping, and coppicing (ICRAF 2008). The mature fruits are edible, and sold from within East Africa in the local markets in Northern Ethiopia and Sudan (Demel Teketay & Abeje Eshete 2004; El-Tahir 2004; ICRAF 2008). The leaves provide fodder in the dry season. The flowers are very good bee forage, and boost honey production wherever the trees are present (Azene et al. 1993; ICRAF 2008; Legesse Negash 1995; Mac Lachlan et al. 2001; Von Breitenbach 1963). As a traditional medicinal plant some literature just note that there is traditional medicinal use of the plant (Birhane et al. 2011; Emmanuel Neba 2010; Smith et al. 1996; Takaoka 2008). More specifically migraine, broken bones, wounds, gastritis and constipation were noted to be treated with bark, leaf and fruit (Zenebe et al. 2012). In more detailed studies illnesses and parts used and how they are used are described. The fresh, juicy bark is used to tie a broken bone; this splint is changed occasionally with a fresh one until the bone is healed (ICRAF 2008; Jansen 1981; Kokwaro 2009; Obeng 2010; Royal Botanic Gardens 2009). In Congo the bark is macerated and used to treat madness via nasal application (Chifundera 2001). A decoction made from the bark is used to treat venereal diseases (Kokwaro 2009) and that of the root to treat bilharzia (Jansen 1981). In another study sterile branches are ingested to treat problems of urination at night (Yirga 2010). The wood and root are used as a vermifuges and the ash as skin and mucosae treatment (Royal Botanic Gardens 2009). In Tanzania the lake Victoria region the root is used to treat tuberculosis, cough and asthma (Otieno et al. 2011). The leaves and root are used to treat liver diseases, the root is used to treat amoebiasis, and root and root bark are used to treat stomach ache and diarrhoea (Giday et al. 2007). For general body ailment inhalation of the boiled leaf vapours is used (Teklehaymanot et al. 2007). The leaves are used ashed and mixed with butter to treat burns and wounds (Jansen 1981; Teklay et al. 2013). The cursed leaf juice is drunk to treat general body ailment, diarrhoea, and tonsillitis and is rubbed into the eye to treat eye infection (Teklay et al. 2013). The crushed leaf is also applied to wounds for healing (Giday et al. 2009). Old wounds are cured using crushed leaves in Tanzania, and intestinal worms are expelled by eating leaves by Masai and Chagga people in East and South Africa (Jansen 1981).

In a detailed chemical analysis the leaves, stem and bark were found to contain polyphenols, tannins and unsaturated sterol/triterpenes. When extracted in water extract at 1000 μg per ml and more, it inhibited *Neisseria gonorrhoea, Streptococcus pyogenous*, and *Stretococcus pneumonia*, while distilled extract inhibited *Neisseria gonorrhoea* at 250 μg per ml concentration and more (Geyid et al. 2005). In another study antifungal properties of the root were tested with brine shrimp lethality, and lethality was achieved at LC_{50} 211.4 (117.6-380.1) μg per ml (Moshi et al. 2007). The sticky gum from the fruit of *C. africana* (*Cordia abyssinica)* was studied with details of its chemical composition, sulphuric acid hydrolysis, 2 M trifluoroacetic acid hydrolysis has been described and the extract was shown to have good emulsifying properties (Benhura & Chidewe 2002; Benhura & Chidewe 2004). Through search of the literature, though the gum from the fruit was used as an emulsifier, no study was thus far found looking at the traditional medicinal value of fruit. Therefore this study set out to investigate this. The objective of this study was to collect information on the traditional medicinal use of *Cordia africana* fruits.

Methodology

Medicinal use survey

Within Tigray area in Ethiopia, *C. africana* is found to grow in different land use systems and agro-ecological zones within the altitude range of 500 to 2700 m.a.s.l. (ICRAF 2008; Obeng 2010). The agro-ecology in Ethiopia is classified based on altitude and rainfall (Hurni 1986). This is because day-length is more or less constant and only temperature and rainfall vary. The temperature and rainfall vary on altitude and the direction of the rain carrying clouds, and the rain carrying clouds come from the Atlantic between June to September and from the Pacific between February-April. *C. africana* is found in areas of Tigray with moist highland, at an altitude of 2300 to 3200 m.a.s.l. and rainfall of 900 to 1400 mL year^{-1}; dry mid highland with altitude 1500 to 2300 m.a.s.l. and rainfall of less 900 and moist mid highland at the same altitude but with rainfall of 900 to 1400 mL year^{-1}; and dry lowland with an altitude less than 1500 m.a.s.l. and rainfall less than 900 mL year^{-1}. The existing study areas where *C. africana* was found were divided into four agro-ecological zones and three land use systems within the four agro-ecological zones. For the selection of the specific study sites, a woreda (second smallest administrative level in Ethiopia) was randomly selected from each of the agro-ecological zones so as to represent the agro-ecological area.
Figure 1 shows an altitudinal map of the Tigray Regional State showing the three different agro-ecological zones based on altitude. Estimated rainfall data were added to this map in order to determine the random selection of the four woredas. However, no adequate number of trees could be found in *Irob* and *Atsbi Womberta* woredas. As a result, two other woredas were selected as substitutes. The final four randomly selected woredas were *Alaje* (moist high altitude), *Hintalo Wajerat* (moist mid-highland), *Laelay Maychew* (dry mid-highland) and *Raya Azebo* (dry lowland). In the four woredas 10 key informants were identified and interviewed and where possible a group of an additional 5 key informants were interviewed. As it was not always possible to get five people together, the group interviews were done with two and three people where applicable. The key informant selection was again done in consultation with the woreda level forestry experts. These key informants were then interviewed, and the information collected was summarised in frequency graphs and tables.

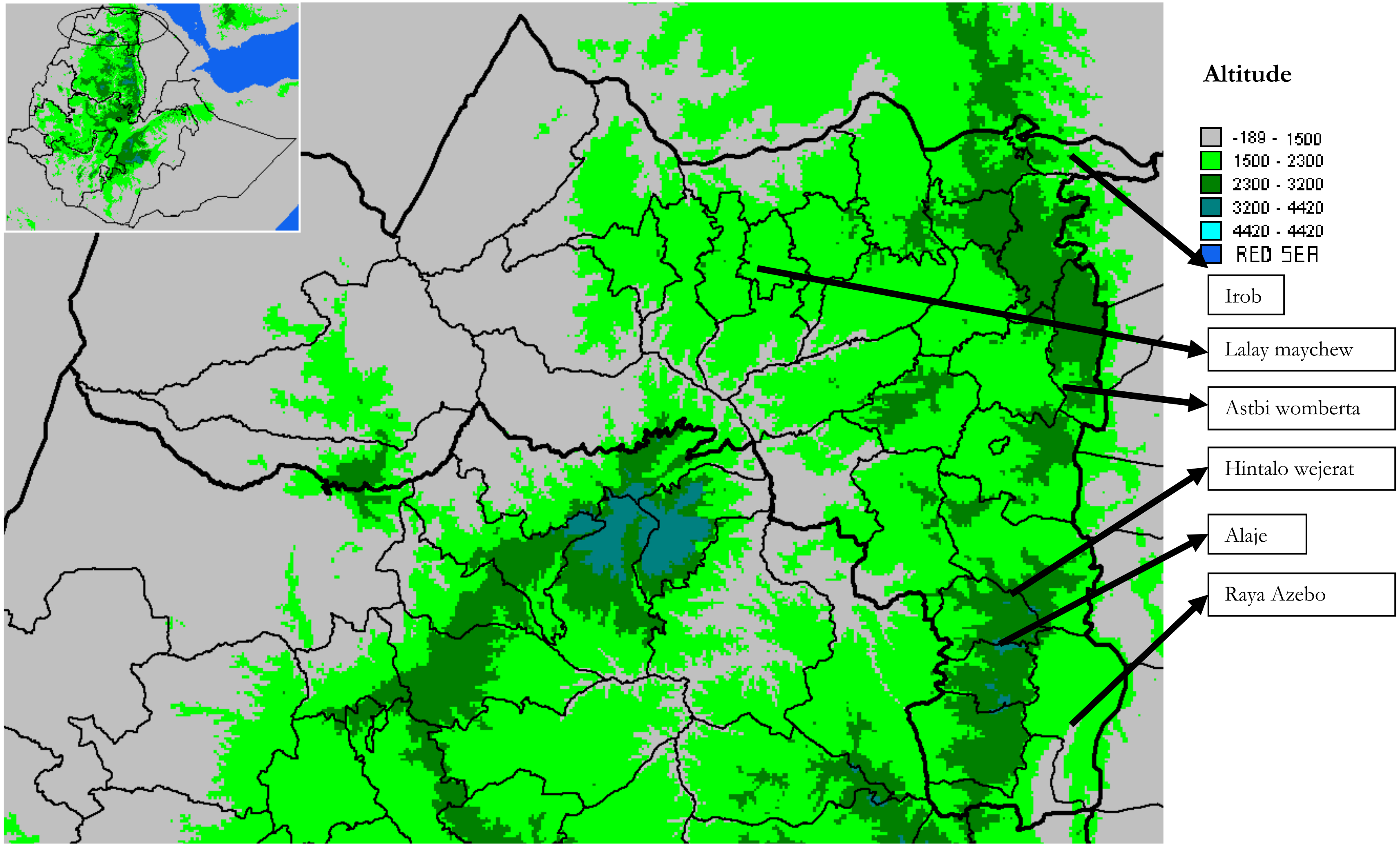

Figure 1. Map of selected woredas in Tigray, Ethiopia, East Africa, showing their relative location and altitude. Generated on the free DIVA-GIS software, (Hijmans et al. 2012).

Results

Description of the sample population

There were a total of 60 people involved in the interview. The result shows that the majority (91.6%) of the people interviewed had lived in their current location from 30 to 70 years of age (Figure 2). The people interviewed who had lived less than 30 years had moved to these places through marriage or re-settlement. As all had been identified by the local forestry expert, it was assumed that they were knowledgeable about the plants and their use in the locality.

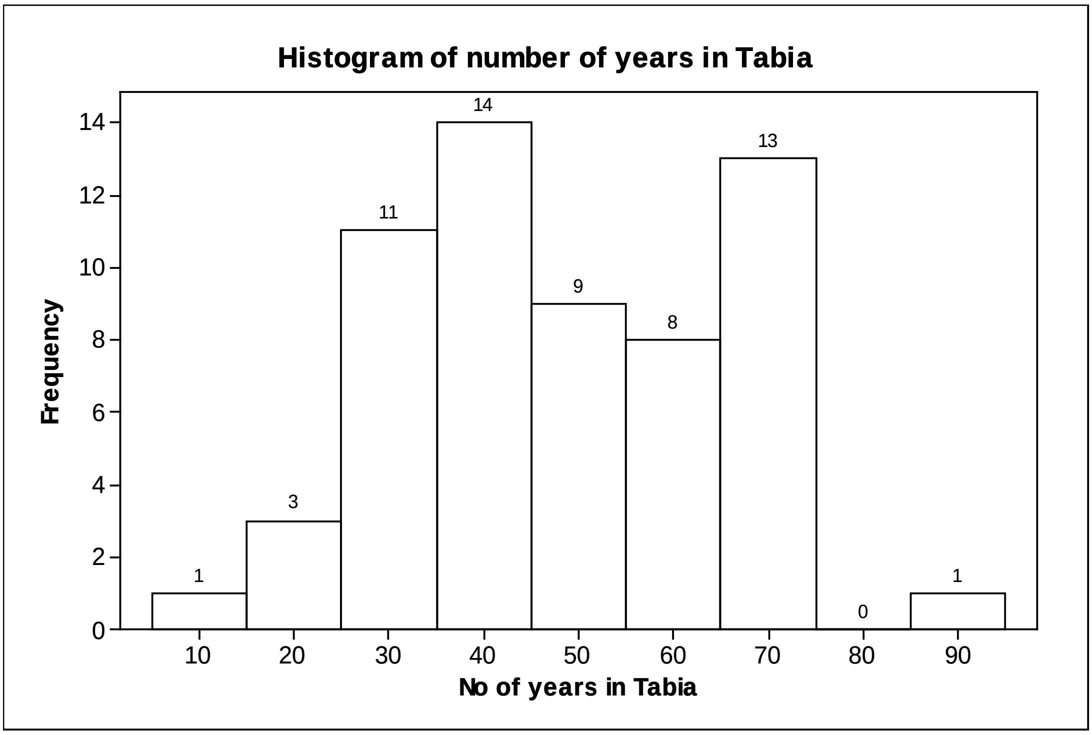

Figure 2 Frequency graph of number of years the people interviewed had lived in their current location

From the 60 people interviewed 49 said they ate the fruit and knew that it was eaten (Figure 3). The 11 people who said they neither ate nor knew the fruit was edible all came from *Raya Azebo* woreda, and this made 73% of all the people interviewed in that woreda.

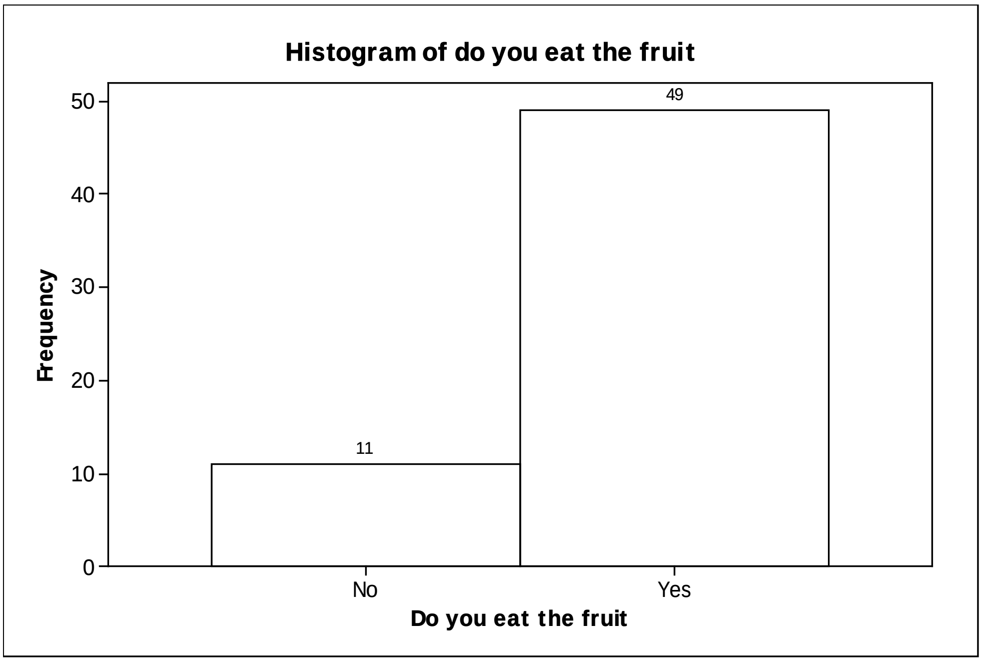

Figure 3 Frequency graph of number of respondents who had and who had not eaten or knew that the fruit was edible.

Of the 60 people interviewed only 33 stated that they knew medicinal uses of *C. africana* (Figure 4). The 33 people mentioned 52 different kinds of illnesses for which the plant could be used.

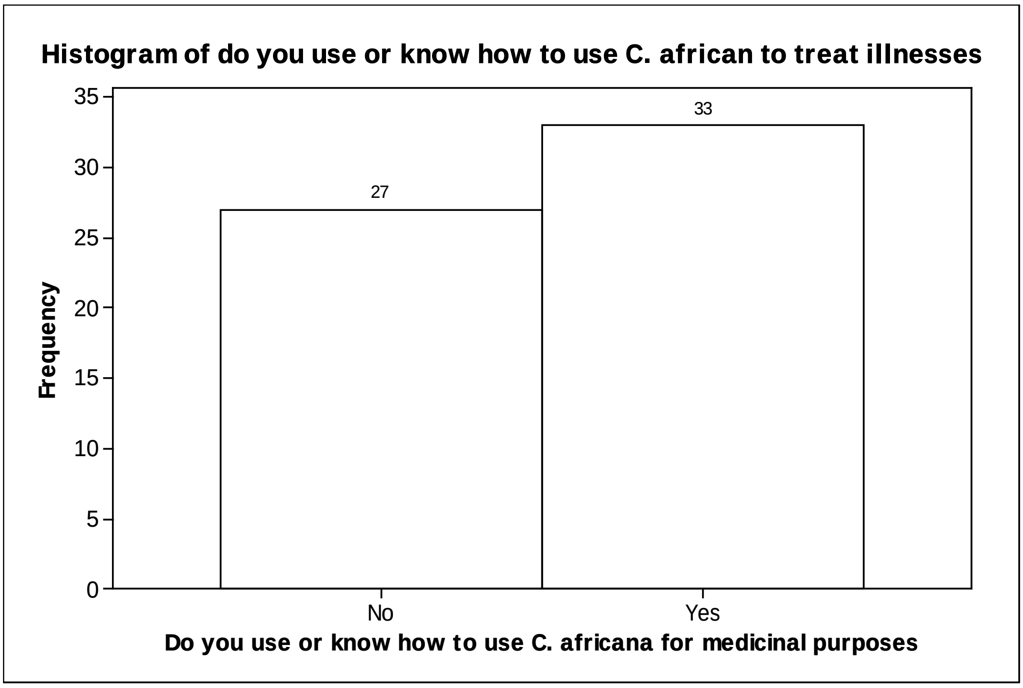

Figure 4: Frequency graph of number of respondents who knew how to use *Cordia africna* to treat illnesses.

Medicinal use of the fruit

The 60 people interviewed were asked to describe the symptoms and illnesses for which they use the fruit as treatment. The results of the responses is summarised in Table 1.

Table 1 Summarized frequency table of the different illnesses and symptoms mentioned as being treated with *Cordia africana*

Symptom mentioned	Lalay Maychew	Emba Alaje	Hintalo Wejerat	Raya Azebo
Gastrointestinal symptoms				
Diarrhea	4 (7.69%)	7 (13.46%)	4 (7.69%)	1 (1.92%)
Abdominal pain	16 (30.77%)	9 (17.31%)	1 (1.92%)	0 (0.00%)
Mouth watering	7 (13.46%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Bloating	16 (30.77%)	1 (1.92%)	1 (1.92%)	0 (0.00%)
Nausea	4 (7.69%)	1 (1.92%)	0 (0.00%)	0 (0.00%)
Weakness related to malnourishment	2 (3.85%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Worms in stools	4 (7.69%)	1 (1.92%)	2 (3.85%)	0 (0.00%)
Abdominal pain relieved with eating	7 (13.46%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Loss of appetite	1 (1.92%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Constipation	0 (0.00%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Number of participants	**28 (53.85%)**	**11 (21.15%)**	**7 (13.46%)**	**1 (1.92%)**
Dermatological symptoms				
Burning pain of skin	0 (0.00%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Dry and sore skin	0 (0.00%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Itchy and sore skin	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (1.92%)
Number of participants	**0 (0.00%)**	**0 (0.00%)**	**2 (3.85%)**	**1 (1.92%)**
Other symptoms				
Jaundice	0 (0.00%)	1 (1.92%)	0 (0.00%)	0 (0.00%)
Sore throat	0 (0.00%)	0 (0.00%)	1 (1.92%)	0 (0.00%)
Number of participants	**0 (0.00%)**	**1 (1.92%)**	**1 (1.92%)**	**0 (0.00%)**
Total number of respondents	**28 (53.85%)**	**12 (23.08%)**	**10 (19.23%)**	**2 (3.85%)**

(Summarized and frequencies determined by a medical doctor, Dr. Lemlem Tewolde-Berhan)

The illness the people name and the symptoms they give do not coincide, for example they name worms in stool for Bilarzia, while it is only blood and eggs that can be found in the stool, and the eggs need microscopes to see. Overall looking at the symptoms and the illnesses mentioned the following groups were identified:

1. Gastrointestinal symptoms: These illnesses were mentioned 47 times by 30 people. In a study on the effect of *Cordia dichotoma* on worms showed promising effects by

killing earth worms (Maisale et al. 2010). In addition extracts of *C. latifolia* is known to have nematicidal activity (Begum et al. 2011). There is a need to study the effect on worms that infect human beings, and if *C. africana* also has the same effect. However, the fact that the local people use it for de-worming and another plant in the same genera is used for similar treatments in India, gives strong indications for possible investigation. In Ethiopia helminths infections is the second most dominant cause of illness caused by drinking poor quality water and low latrine coverage (Alemu et al. 2011). In this setting the government with the help of the World Bank and other partners runs yearly de-worming campaigns focusing on children aged 5 and less (Alemu et al. 2011; Lagler et al. 2010). In addition the consumption of fibre is known to help reduce constipation (Dukas et al. 2003; Loening-Baucke et al. 2004; Stark & Madar 1994), and as the fruits are consumed whole and the fruit stone acts as a bulking in the intestines. The help of eating the fruit in reducing constipation merits further study.

2. Liver problems and jaundice was mentioned by only one person, however the same use was mentioned by traditional people in Ethiopia (Giday et al. 2007; Teklay et al. 2013).
3. Dermatological symptoms: Skin burns, sores and infections were mentioned by three people.
4. Tonsillitis was mentioned by only one person.

To treat the above mentioned illnesses, the parts of the plant used (Table 2), method of plant preparation (Table 3), method of administration and frequency of use per occurrence (Table 4), and other things that may be combined with the plant (Table 5) were investigated and are summarised below.

Table 2, Part of *C. africana* plan used to treat illnesses mentioned

Part of plant used	Frequency	Method prepared and frequency of use
Fruit	34	Both fresh and dried, fresh is preferred; varied amounts eaten mostly on empty stomach
Young leaves	17	Crushed to extract juice and drunk on an empty stomach
Leaves	1	Crushed or dried powder applied to skin
Total	52	

As can be seen in Table 2, the most frequently mentioned part of the plant used is the fruit, which corresponds with the most mentioned problem, which are intestinal related infestations and infection. It should be noted here that the questions had also been specifically addressing the fruit, and thus other plant-parts mentioned here were done so despite that fact. The leaves here are related to treating the mentioned stomach and skin problems. In a study done looking at the leaves, bark and stem of *C. africana*, it was found that the distilled and water extract had anti-bacterial activity, and active compounds polyphenols, tannins and unsaturated sterol/triterpens were identified (Geyid et al. 2005).

Table 3 Method of preparation of the *C. africana* plant-part used to treat illnesses mentioned

Method of plant preparation	Frequency	Valid Percent	Cumulative Percent
Bring the fruit to boil with salt and sugar	1	1.9	1.9
Collect leaves, burn and keep to mix with fresh butter when needed	1	1.9	3.8
Fresh and dry fruit	18	34.6	38.5
Fresh fruit	15	28.8	67.3
Fresh leaves	1	1.9	69.2
Grinding or pounding of the leaves and mixing the juice with coffee	1	1.9	71.2
Grinding or pounding the young leaves and mixing the juice with coffee	12	23.1	94.2
Grinding or pounding the leaves and the root of *Atush* (*Achyrantes aspera/Verbena officinalis*) and mixing the juice with water	1	1.9	96.2
Pound and dry leaves and use when needed	1	1.9	98.1
Soaking (both fresh and dry fruits) in water and honey, especially with white honey	1	1.9	100.0
Total	52	100.0	

The table above shows that both the dry and fresh fruits are used, though there was a clear preference toward the use of the fresh fruits. The fruits were mostly swallowed whole. The leaves were also used both dried and fresh; the juice of which was used after crushing; or were pound and mixed with coffee, *Atush*, butter.

Table 4 Method of administration of the *C. africana* plant-part used to treat illnesses mentioned

Method of administration	Frequency	Valid Percent	Cumulative Percent
Leaves: anytime for skin problem (1 or 2 times)	1	2.0	2.0
Leaves: anytime one has stomach problem during the day until healed	1	2.0	3.9
Leaves: apply like a cream and cover with a clean cloth for skin problem (1 or 2 times)	1	2.0	5.9
Leaves: apply like cream on the burn when needed	1	2.0	7.8
Leaves: burn fresh leaves to fumigate the skin (1 time or more as needed)	1	2.0	9.8
Leaves: drinking the crushed leaf extract (1 to 2 days on an empty stomach)	1	2.0	11.8
Leaves: drinking the extract in the morning on an empty stomach (1 to 2 days on an empty stomach)	11	21.6	33.3
Fruit: drinking the extract in the morning on an empty stomach, and during the day when needed (2 days on an empty stomach)	1	2.0	35.3
Fruit: eating them whole (for 1 week)	1	2.0	37.3
Fruit: eating 1 0.7 kg on an empty stomach (3 to 4 days in a row on an empty stomach)	2	3.9	41.2
Fruit: eating a hand full on an empty stomach (4 to 5 days in a row on an empty stomach)	4	7.8	49.0
Fruit: eating 0.35 to 0.7 kg on an empty stomach (4 to 5 days in a row on an empty stomach)	3	5.9	54.9
Fruit: eating on an empty stomach (4 to 5 days in a row on an empty stomach)	18	35.3	90.2
Fruit: eating two hand full's or 0.35 kg on an empty stomach (repeat until healed)	5	9.8	100.0
Total	51	100.0	

The majority of the responses indicate the consumption of the fruit on an empty stomach to be preferable, though there were different timings. The leaf extracts were also mentioned as being preferred to be taken on an empty stomach, this will be to make the acting components consumed more effective as they will not be diluted and will be the only substances present in the gut. The skin applications took the form of mixing with butter to make a cream or fumigation. The amount of fruit eaten and juice drank varied strongly while some were not even willing to say how much and how often. The frequency of use again varies, but there is a maximum use of up to a week with the minimum being once. The most frequently mentioned frequency being once, followed by, up to three days making up 70.6% of the response.

Table 5 Other things used in combination with *Cordia africana* to treat the different illnesses mentioned

Thing used	Frequency	Valid Percent	Cumulative Percent
Atush (*Achyrantes aspera/Verbena officinalis*)	1	1.9	1.9
Clean fresh butter	2	3.8	5.8
Honey	2	3.8	9.6
Hot coffee	1	1.9	11.5
Nothing/alone	46	88.5	100.0
Total	52	100.0	

The majority of the respondents stated that they used *Cordia africana* alone, *Atush* was used for treating stomach upsets and diarrhea in combination with the leaves of *Cordia africana*. Clean fresh butter was used in combination with the leaves to treat sores and skin burn. The honey was used in combination with the fruit for de-worming. The hot coffee was used in combination with the young leaves to treat diarrhea in children up to 6 years of age.

4. Conclusion

The search of literature showed that there is actually verified use of the leaves, stem and bark of *C. africana*. This survey showed that the local communities in Tigray also use the fruit for medicinal purposes. Though the descriptions were ambiguous it was clear that the fruits were used whole for the treatment of gastro-intestinal ailments. As *Cordia dichotoma* has proved anthelmintic properties and the fruit of *C. africana* coming from the same genera probably has similar properties. The fruit as it is consumed whole and has a large stone, with the claim that it helps with constipation may have some merit. As the fruit has been used as a food source for centuries with no side effects it shows great potential for further study. In the Ethiopian setting and the de-worming campaigns, the results of such a study will be useful.

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