GENOTYPIC-ENVIRONMENTAL EFFECTS ON NUT PICKING DURATION, YIELD AND QUALITY OF SEVEN CASHEW (*Anacardium occidentale* L.) CLONES IN SOUTH-EASTERN TANZANIA

BY

FORTUNUS KAPINGA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2009

ABSTRACT

An experiment was conducted in 2007/08 season at Naliendele, Nyangao and Nanyanga sites in South-Eastern Tanzania, to determine genotypic-environmental effects on nut picking duration, yield and quality of seven cashew (*Anacardium occidentale* L.) clones. The experiment was laid out in a Randomized Complete Block Design, with two factors arranged in split plot experiment; in which locations were the main-plot while clones replicated four times were the sub-plot treatments. Cutting-test carried out at NARI was used to determine nut physical quality. Nutritional values in the cashew kernels were evaluated at SUA, where fats and protein were analysed in DASP laboratory using *Soxhlet Continuous Extraction* and *Kjeldalh* methods, respectively. Minerals were analysed in soil science laboratory, where U-Visible Spectrometer was used to determine phosphorus content while atomic absorption spectrum was used to measure the quantities of calcium, magnesium, iron, zinc and copper. Flame photometer was used to measure potassium and sodium contents. Significant variations ($P \leq 0.05$) among clones were observed in all parameters studied. Clone AZA17 consistently had the shortest nut picking duration in all sites, with an overall mean of 47 days. Cashew clone AC4 showed early crop maturity at Naliendele and Nanyanga, while clone AC4/285 matured early at Nyangao. The highest yield (3512.2 kg/ha) across the locations was produced by the clone AC4/285. Naliendele was considered most suitable site for cashew nut production because it gave the highest overall mean cashew nut yield (3530.0 kg/ha). Clone AC10 outperformed in nut weight (9.3 g), fat and protein contents. On the other hand, clone AC14 was superior in mineral composition across the locations. This study also revealed that, high nut yielding clones are poor in nutrient contents. High yielding clones with short nut picking duration and early maturity characteristic were found to be important selection criteria for economical cashew nut production.

DECLARATION

I, Fortunus Kapinga do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and has not been submitted for a degree award in any other University.

.... 19. 10. 2009 ....

Fortunus Kapinga (M.Sc. Candidate)

Date

The above declaration is confirmed

.... 19. 10. 2009 ....

Prof. R. N. Misangu (Supervisor)

Date

COPYRIGHT

ACKNOWLEDGEMENT

I thank the Government of United Republic of Tanzania, for allowing the Department of Research and Training of Ministry of Agriculture, Food Security and Co-operatives to offer me a sponsorship in this postgraduate study.

I would like also to thank Dr S. H. Shomari, the Zonal Director of Agricultural Research and Training (Southern Zone) for permitting me to be away from my working station (NARI), for this further study.

I am very grateful to my supervisor, Prof. R. N. Misangu for his close guidance throughout the period of my research work.

I am also thankful to Prof. S. O. W. M. Reuben and Prof. E. E. Maeda for sparing their precious time to pass through my path coefficient analysis and give valuable comments.

I acknowledge Dr P. A. L. Masawe for his technical advices related to cashew breeding. I would like also to thank staff members in cashew breeding section, Mr W. Kilali and Mr A. Mwinuka, for their heartily assistance in field data collection. I also thank my fellow workers of NARI as their co-operation has in one way or another assisted me to accomplish this work successfully. Many people helped me in different ways during this research work. Since it is difficult to mention them all in this single page, I would like to emphasize that it would not have been possible to complete this work without their co-operation. So, I thank them all.

DEDICATION

This work is dedicated to my wife A. F. Chale. She was always there being a source of my joy, by giving me support and encouragement. I also dedicate to Eric, Anton, Bernadina, Shanel, Filomon, Arecy, Elizabeth and Chanai for their co-operation, patience, motivation and prayers during my absence for MSc studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATION AND SYMBOLS

%	percent
ANOVA	Analysis of Variance
CDC	Cashew Development Centre
Cl	Chlorine
cm	centimetre
CNSL	Cashew nut shell liquid
CRFG	California Rare Fruit Growers, Inc.
CRP	Cashew Research Programme
DASP	Department of Animal Science and Production
DCCD	Directorate of Cashewnut & Cocoa Development
DoA	Department of Agriculture
FAO	Food and Agriculture Organization
g	grams
GDV	Gesamtverband der Deutschen Versicherungswirtschaft e.V.
H_2O	Water
ha	hectare
HCl	Hydrochloric acid
hr	hour
IRRI	International Rice Research Institute
kg	kilograms
km	kilometre
m	metre

masl	Metres above sea level
mg	milligram
ml	millilitre
mm	millimetre
MT	Metric tones
NARI	Naliendele Agricultural Research Institute
NLU	Nong Lam University
nm	nona-metre
°C	Degree Celsius
QG	Queensland Government
SADOCC	Southern Africa Documentation and Cooperation Centre.
SG	Standard grade
SUA	Skoine University of Agriculture
TFM	The Food Museum
TGMF	The George Mateljan Foundation
TNF	The Nut Factory
TNU	Tay Nguyen University
UG	Under grade
UN	United Nation
US$	United States Dollar
USA	United States of America
VUAT	Virtual University of Agricultural Trade

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Cashew (*Anacardium occidentale* L.) is one of the important perennial tree crops, grown in tropical countries especially Brazil, Vietnam, India, Eastern and Western Africa. In Africa, it is estimated that about 3,000,000 households are involved in cashew nut production with an average of 3 ha per household (NARI, 2007). In Tanzania, more than 300,000 households are estimated to be engaged in cashew nut production (NARI, 2006).

Cashew nut is the main source of cash income for smallholder farmers along the coast of Tanzania. The smallholder farmers comprise of over 280,000 households in South-Eastern Tanzania, which contribute over 80% of cashew nut produced in the country (Masawe, 2006; Mwangu, 2007). According to Mwangu (2007), about 400,000 hectares of cashew are distributed in 33 districts in Tanzania.

Cashew is one of the most important export crops in Tanzania in terms of foreign exchange earnings replacing coffee that dominated since 1960s (Masawe, 2006). Tanzania's cashew industry generates 5% of the country's export earnings - approximately $70 million annually - from raw cashew nut exports (MBendi, 2004; Wakabi, 2004). On top of that, cashew creates employments; not only to farming communities, but it also employs peoples in cashew nut processing factories (Mhagama, B. personal communication, 2007).

In addition, cashew nuts kernels have good nutritional values to human beings. They are a rich source of vitamins (A, D and E), fats, protein, iron, calcium, and phosphorus. Due to its high value, even small pieces find a market in confectionery products (FAO, 2006, 2008). Cashew nuts are common appetizers, like peanuts and pistachio nuts. The product is also used in the food industry as an ingredient in chocolate and ice cream. Apart from the nut, the cashew apple is used to make juice (Rocha, 2006). Some cashew genotypes bear sweet apples, which are consumed as fresh fruits. Moreover, cashew apples are used as supplementary animal feeds. Cashew apples can also be fermented or distilled to make alcoholic drinks (DCCD, 2008).

However, despite of these usefulness, in Tanzania, research records on cashew production have indicated low yield due to several reasons, including poor yield potential and aging of some cashew genotypes. For example, it is estimated that more than 80% of the total cashew trees available in Tanzania were planted in the early 1950s. Owing to this old age, the trees have lost their yielding potential, which contributed to the decline in nut yield from 145,000 tones in 1973/74 season to 16,000 tones in 1986/87 season (NARI, 2007). Adoption of cashew farmers to growing improved cashew clones led to increase in cashew nut production from the 16,000 tones in 1986/87 season to 120,000 tones in 2000/01 season (NARI, 2007). Nevertheless, at the moment I was conducting this study, the production was fluctuating below the record obtained in the 1973/74 season (Fig. 1).

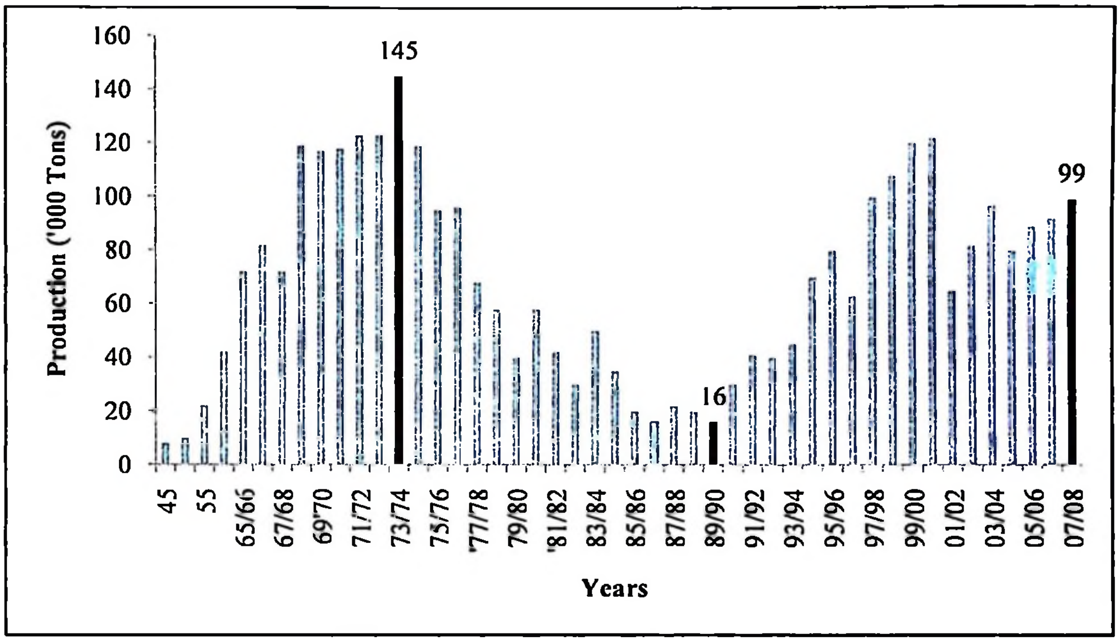


Figure 1. Cashew nut production in Tanzania from 1945 – 2007/08 season

Source: CRP Annual Report, 2007/08 Season

Regardless of the decline in cashew production in the past two decades, cashew nuts still remains the third important export crop of the country. Furthermore, Tanzania maintains its position as the fourth biggest cashew nut producer in the world (Premier, 2008).

On the other hand, although growing of improved cashew genotypes have shown an increase of cashew nut yield, there are several other constraints (such as costs that are incurred to pay for insecticides, fungicides, weeding, pruning, nut picking, grading, transport charges, packing materials and security guard), which minimize net revenue. Cashew growing farmers are aware of these hurdles. Unfortunately, cashew nut picking duration for particular genotypes is either neglected or not put into account, despite of its contribution in minimizing the net revenue of the cashew nuts produced. The cashew nut picking duration can be explained based on time length and time of attaining the highest yield proportion. These aspects have impact on the cashew nut yield, quality and the revenue.

According to Foltan and Lüdders (1995), anthesis (the period of time between the opening of a flower and the formation of the fruit) usually extends over a period of 4 to 5 months. In course of the anthesis, flowering of hermaphrodite and male flowers occur in sequential phases (Rao and Hassan, 1957; Moncur and Wait, 1986). However, the flowering characteristics depend on genotypes. Within a season, some genotypes flower early with either short or long anthesis, while others flower late with anthesis categories similar to the early flowering genotypes. This implies that the longer the anthesis, the longer the nut picking duration.

The problem, which is experienced in such enormous variations in performance of cashew genotypes, is that some of the cashew nuts mature during the rain or near to the rain season. This consequently leads to deterioration of nut quality at harvest. Moreover, farmers who grow cashew genotypes with prolonged anthesis spend a lot of time to complete nut picking. Nevertheless, at the end of the season, farmers end up with nut yield similar to the one that could be picked within a short time if they could grow genotypes with short cashew nut picking duration. Since cashew nut picking duration depends on genotypes and weather conditions, it is important to assess the influence of genotype and environment on cashew nut picking duration, and their implications on nut yield and quality.

1.2 Problem statement

Profit maximization in cashew nut production is considerably affected at harvesting, as it generally takes very long time (about six months) to complete this operation. Moreover, spending much time on cashew nut picking affects other activities such as cashew nut grading and land preparation for growing annual crops such as cassava and cowpeas for food consumption. Although researches have been carried out in Tanzania to evaluate cashew nut yield and physical nut quality per season, preliminary studies conducted at Naliendele have shown existence of variation in nut picking duration among cashew genotypes. However, no study has been conducted to assess the influence of genotype, environment and their interaction on the cashew nut picking duration, with special attention on both nut yield in the given duration and nutritional quality of the kernels.

1.3 Justification

Frequent picking of small quantities of nuts in the field is not economical. On the other hand, if the soil is wet leaving nuts on ground for at least two days, results into deterioration of the nuts. The nuts are also at risk of being stolen; otherwise farmers have to employ security guard, which implies an additional cost of production. Harvesting costs incurred are highly influenced by nut picking duration. Cultivars with prolonged period of nut picking sometimes require extra rounds of weeding or clearing the ground for easy and efficient collection of the crop. This extra task increases harvesting cost, and suggests that farmers growing cashew varieties with long nut picking duration incur high harvesting cost. Moreover, low nut yield and quality due to poor performing cashew genotypes, contributes to inadequate return to cashew growers. In view of these typical problems, there is a need of having further understanding of genotype, environment and their interaction effects on duration of nut picking of various cashew genotypes and their implication on nut yield and quality. This study aimed at identifying and selecting cashew clones with short duration of nut picking, but with high performance in nut yield and quality. The characteristics may in future be incorporated in breeding programs.

1.4 Overall objective

To establish the influence of genotype and environment on nut picking duration of seven cashew clones in South-Eastern Tanzania, and its implication on nut yield and quality.

1.5 Specific objectives

(i) To determine time taken to complete nut picking and attaining the highest yield proportion of seven cashew clones at three locations (Naliendele, Nanyanga and Nyangao) in South-Eastern Tanzania

(ii) To determine cashew nut yield of the seven clones

(iii) To assess physical and nutritional nut quality of the seven cashew clones.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of cashew

The cashew tree is believed to originate in South America, from where it was introduced to many other areas of the world (Ohler, 1979); and it is considered as a native to Brazil in the area between the Atlantic rainforest and the Amazon rainforest (Azam-Ali and Judge, 2002). Cashew is said to be discovered by European traders and explorers and first recorded in 1578 (Taylor, 2005). Although cashew domestication existed before the arrival of the Europeans to Brazil (Rieger, 2006), Portuguese, who invaded Brazil in the 1500s, are the first western people considered in sighting the cashew tree (TNF, 2008).

The Portuguese introduced cashew to the west coast of India and East Africa in the 16th century, shortly after its discovery in 1578 (Rieger, 2006). In the beginning cashew was mainly considered as a crop for afforestation and control of soil erosion along the cost (VUAT, 2007; Keralaagriculture, 2008). Therefore, the aim of this introduction was not to produce nuts and apples (pseudo-fruit), but to help control soil erosion along the coastal regions of these countries (Woodroof, 1979). Use of the nuts and pseudo fruits were developed much later, and the international nut trade did not occur until the 1920s (Rieger, 2006).

The first introduction of cashew in India was made in Goa from where it spread to other parts of the country (VUAT, 2008). Portuguese seamen brought the seeds of the cashew nut tree from Brazil to the east coast of Africa where they were planted along the coast by early settlers. The cashew trees grew wild along the entire coast of Mozambique, and later spread to Tanzania and Kenya (TNF, 2008).

In Tanzania, (by then Tanganyika), cashew germplasm was introduced to Nachingwea (Lindi region) in the 1950s (Kasuga, 2003). Cashew has spread over years either naturally or through smallholder's cultivation (NARI, 2007). Elephants that ate the cashew apple along with the attached nuts are some of the agents considered to spread cashew within these countries, as the nuts were too hard to digest and were later expelled with the droppings (Azam-Ali and Judge, 2002). Wild birds and fruit bats carry off cashew apples, and drop the leftovers. They are also regarded as responsible for cashew spread, (Bradtke, 2007).

The cashew tree is now cultivated in all regions with a sufficiently warm and humid climate (Wikipedia, 2008). In Tanzania, cashew is mainly grown along the coastal area (Appendix 1). However, because of its adaptive ability in wide range of agro climatic conditions and the increase in its economic importance, today even some non-traditional cashew growing areas (such as Dodoma, Iringa, Mbeya, Singida, Morogoro, Mbarali, Mbinga and Songea) have started planting cashew trees (Masawe, 2006).

2.2 Uses of cashew

Cashew is a versatile or multipurpose tree (Azam-Ali and Judge, 2002). Many parts of the cashew plant are used, including the cashew tree as it produces many resources and products (Duke, 1983). However, the nut is considered the most valuable product of the cashew tree, and it is the main commercial product of the cashew tree, though yields of the cashew apple are eight to ten times the weight of the raw nuts (VUAT, 2008). Three main cashew products traded on the international market are raw cashew nuts, cashew kernels and cashew nut shell liquid (CNSL), which is released as by-product during processing (Azam-Ali and Judge, 2002).

The raw nuts are either exported or processed prior to export (Azam-Ali and Judge, 2002). The cashew nut shell liquid (CNSL) is a black, acrid, powerful vesicant, inedible oil (poisonous) found between the seed coat (or pericarp) and the nut. It represents 15% of the gross weight (VUAT, 2008). CNSL is one of the few natural resins (natural secreted organic substance) that are highly heat resistant. It is used medicinally and it finds use in industry as a raw material for brake lining compounds, as a water-proofing agent, a preservative, and in the manufacturing of paints, resin and plastics (FAO, 2008; Taylor, 2005). According to Duke (1983), the CNSL is used as a preservative and water-proofing agent in insulating varnishes, in manufacture of typewriter rolls, in oil- and acid-proof cements and tiles, in brake-linings, as an excellent lubricant in magneto armatures in airplanes, and for termite proofing timbers. The skin of the nut is high in tannins and can be recovered and used in the tanning of hides (Azam-Ali and Judge, 2002).

In addition, the CNSL is also used to derive various chemicals such as cardanol, residol, cardol and anacardic acid (Cashew.in, 2006). Medicinally, CNSL contains a compound known as anacardium, which is used to treat dermatological disorders

(VUAT, 2008). Moreover, cashew nuts are antiseptic, antibacterial, anti-fungal, anti-parasitic, and their roots are purgative (Cashew.in, 2006).

In the world's production of edible tree nuts, cashew ranks third (Cashew.in, 2006). Edible pale yellow, bland and edible oil, resembling almond oil can be extracted from cashew nuts. However, the oil from the cashew kernel is in rare cases derived (CRFG, 1995; Cashew.in, 2006). It is estimated that 60 percent of cashew kernels are consumed in the form of snacks while the remaining 40 percent are included in confectionery products (VUAT, 2008; FAO, 2008). Cashew nut competes in the same market as other edible nuts including almonds, hazels, walnuts, pecans, macadamias, pistachios and peanuts (Keralaagriculture, 2008; VUAT, 2008).

The cashew not only produces an edible nut, but also a nutritive, edible "apple" (NutsOnline, 2008). In the field, the apples are picked up and chewed for refreshment, the juice swallowed, and the fibrous residue discarded (Morton, 1987). Alternatively, they can be used to produce syrups, vinegar, candy, jam, chutney and alcoholic beverages (Duke, 1983; QG, 2008; Taylor, 2005). Processing methods or disposal of the apples depends on the place where they are produced or utilized. For instance, in Goa, India, the apples are trampled by foot to extract the juice for the locally famous distilled liquor, *feni*. In other places, after detaching (twisting off) nuts from apples, the apples are left on ground for livestock grazing (Morton, 1987). The wine made from the juice is said to be the finest wine made from tropical fruits (FAO, 2004; Rieger, 2006).

The bark and leaves of the tree are used medicinally (Taylor, 2005), and used also in the conversion of animal skins and hides into leather (tanning). Stems exude a clear gum, *cashawa* gum, used in pharmaceuticals and as substitute for ***gum arabic***. Juice turns black on exposure to air and provides an indelible ink (Duke, 1983). In other parts of the world such as along the coast of Orissa, cashew trees are planted as shelter belts and wind breaks, to stabilize sand dunes and protect the adjacent fertile agricultural land (Duke, 1983). Timber is used in furniture making, boat building, packing cases and in the production of charcoal (Duke, 1983).

Moreover, the importance of cashew is held with great esteem in many customs and cultures. In Mozambique, the Maconde tribe, for example, refer to it as the 'Devil's Nut'. It is offered at wedding ceremonies as a token of fertility and is considered to have aphrodisiac properties (Azam-Ali and Judge, 2002).

2.3 Nutritional values of cashew kernels

Cashew is a nutritious tropical tree nut. For instance, cashew kernels contain protein (21.00%), fat (47.00%), moisture (5.90%), carbohydrates (22.00%), calcium (0.05%) and iron (5.00/100g) (DCCD, 2008). Moreover, 100 g of cashew kernels contains magnesium 260.0 mg, phosphorus 490.0 mg, potassium 565.0 mg, sodium 16.0 mg, zinc 5.6 mg, copper 2.2 mg (Rawcreation Ltd & Shazzie, 2008). According to Wikipedia (2008), 100 g of some cashew kernels contains fats (43.85%), protein (18.22%), calcium 37 mg, iron 6.68 mg, magnesium 292 mg, phosphorus 593 mg, potassium 660 mg and zinc 5.78 mg.

Cashew contains calcium and magnesium, which are important for bone building up. Calcium is necessary for strong bones. On the other hand, magnesium is also vital for healthy bones. About two-thirds of the magnesium in the human body is found in our bones (TGMF, 2008). Some of the magnesium is used in giving desirable bones physical structure, while the rest is found on the surface of the bone where it is stored for the body to draw upon as needed. Magnesium, by balancing calcium, helps regulate nerve and muscle tone. In many nerve cells, magnesium serves as nature's own calcium channel blocker, preventing calcium from rushing into the nerve cell and activating the nerve. By blocking calcium's entry, magnesium keeps our nerves (and the blood vessels and muscles they enervate) relaxed (TGMF, 2008).

If a diet provides too little magnesium, however, calcium can gain free entry, and the nerve cell can become over activated, sending too many messages and causing excessive contraction (TGMF, 2008). Eating cashew nut kernels can also help to prevent gallstones, lower risk of weight gain (TGMF, 2008; Meyers, 2008). It also provides essential fatty acids, B vitamins, fibre, protein, carbohydrate, potassium, iron, and zinc (Kohler, 1998).

The cashew kernels are heart-protective monounsaturated fats. They also provide copper for antioxidant defences, energy production, bones and blood vessels. As an essential component of many enzymes, copper plays a role in a wide range of physiological processes including iron utilization, elimination of free radicals, development of bone and connective tissue, and the production of the hair and skin pigment called melanin (TGMF, 2008).

Inadequate intake of copper can lead to health problems such as: iron deficiency anaemia, ruptured blood vessels, osteoporosis, joint problems such as rheumatoid arthritis, brain disturbances, elevated cholesterol levels, irregular heartbeat and increased susceptibility to infections. Insufficient magnesium can contribute to: high blood pressure, muscle spasms migraine headaches, muscle cramps, tension, soreness and fatigue (Meyers, 2008).

2.4 Botanical description

The cashew (*A. occidentale*), belongs to the Anacardiaceae family, which is composed of some 60 to 74 genera and 400 to 600 species. This family is characterized by resinous conduits in the cortex and wood, where resin is produced, although exudation also occurs from the leaves, flowers and fruits (Bezerra *et. al.*; 2007). The cashew tree is a tropical evergreen, resistant to drought, unexacting as to soil (although it prefers deep, sandy soil). The tree is generally single-trunked and spreading habit, with extensive root system which helps it to tolerate a wide range of moisture levels and soil types. In older trees, spread may be greater than height with lower limbs having a symmetrical spread of up to approximately 25 metres bending to touch the ground. Leaves are thick, prominently veined, and oval to spatulate in shape, with blunt tips and entire margins (FAO, 2004; TNF, 2008; Azam-Ali and Judge, 2002; GDV, 2008; Google, 2007).

In nature, two types of cashew trees exist classified as *A. occidentale* L. species, each defined by size and denominated as the common type and the dwarf type. The common cashew tree is more widespread and much taller, with a height varying from 8 to 15 m and a crown span that can reach 20 m (Kilali, W. personal communication, 2007). The dwarf cashew tree is characterized by growth that begins earlier in the season, its smaller size and early productivity. Other characteristics that differentiate the dwarf cashew tree from the common type are: a compact and homogenous crown, with an average span reaching approximately twice the height; smaller, lighter green leaves; smaller stem diameter; initial branches closer to the ground; early seasonal flowering; a prolonged period of fructification; smaller nuts; and generally larger peduncles (Bezerra, *et al*, 2007).

Cashew trees flower once a year. The flowers are small, white or red in colour, and grow in clusters (Cashew.in, 2006). Flowering is similar to the close relative mango: both male and perfect (bisexual) flowers are borne in the same cluster or inflorescence (polygamous). The flowers are borne terminally on panicles, generally at the beginning of the dry season (FAO, 2004). In various degrees of development, flowers and fruits are often present in same panicle (Duke, 1983). Seedling trees normally flower in the third year after planting (DoA, 2000). Grafted seedling can flower in same year of planting depending on the scion used in grafting and management (Masawe, 2006). Flowering is affected by weather conditions and also varies from tree to tree. It occurs over several weeks and may continue for a period of 2 to 3 months. High temperatures lead to earlier flowering (Google, 2007).

Pollination is mostly by insects, though wind also plays a great role. Pollinated flowers develop into a light green seed. After pollination it takes 6 to 8 weeks for the fruit to develop (Cashew.in, 2006). The cashew fruit consists of a peduncle (known as the cashew apple) and a seed. The seed develops below a fleshy, swollen peduncle. It is kidney shaped and resembles a large bean or shaped like a small boxing glove, about 2.0 – 4.0 cm long (FAO, 2008; Azam-Ali and Judge, 2002).

An interesting feature of the cashew is that the nut develops first from the cashew flower and when it is full-grown but not yet ripe, its peduncle (or more technically, receptacle), fills out, becomes plump, fleshy, pear-shaped or rhomboid-to-ovate, approximately 5 - 11.25 cm in length, with waxy, yellow, red, or red-and-yellow skin and spongy, fibrous, very juicy, astringent, acid to sub-acid, yellow pulp (Morton, 1987; FAO, 2008). The receptacle is located between the nut and the stem. It develops into a pear-shaped cashew apple within a month (Cashew.in, 2006). The fruit matures about two months later (Google, 2007; NutsOnline, 2008).

Botanically, the cashew apple is not a true fruit, it is rather known as false fruit or pseudo-fruit. The true botanical fruit is the kidney shaped nut. The nut shell is about 5 mm thick, and has an inner and outer wall, separated by a honeycomb tissue infused with caustic oil liquid known as cashew nut shell liquid (CNSL). The fruits are borne singly or in small clusters, and mature in 60 - 90 days (FAO, 2008; Azam-Ali and Judge, 2002; Taylor, 2005; Wikipedia, 2008; FAO, 2004); GDV, 2008; DoA, 2000; Google, 2007; Armstrong, 2004). Weights of apples are normally ten times the weight nuts. Average weight of nuts varies from 6 to 8 g, while apples vary from 50 to 80 g (QG, 2008; DCCD, 2007).

The cashew nut has two shells: a hard exterior shell and a testa. The testa is a thin brown skin (or a fine, brown seed coat), inside the hard shell, and is wrapped around a slightly curved white cashew kernel. It protects the kernel from penetration by atmospheric oxygen so preventing it from becoming rancid (oxidative rancidity) as it contains antioxidants. The skin called a testa is removed during the processing (TNF, 2008).

2.5 Ecological requirements

Cashew growth and yield is influenced by the environment (climate, soil, culture). The cashew tree is a strong tropical evergreen, resistant to drought, renowned (famous) for growing in almost all types of soils from sandy to laterite soils, including wastelands of low fertility, that are generally unsuitable for other fruit trees (Google, 2007; Azam-Ali and Judge, 2002; FAO, 2004; VUAT, 2007). Cashew trees are often found growing wild on the drier sandy soils in the central plains of Brazil (Taylor, 2005). Although the tree has an extensive root system, which helps it to tolerate a wide range of moisture levels and soil types, but for the best production is only advisable to grow it in deep, well-drained, sandy loam or red soils and light coastal sands, with optimum soil pH 4.5 - 6.5 (Google, 2007; Azam-Ali and Judge, 2002; VUAT, 2007; FAO, 2004; NARI, 2007). Minimum soil pH is 3.8. Soils with depth greater than 2 m are recommended for cashew nut production (NARI, 2007). Heavy clay soils or limestone and poor drainage conditions are unsuitable for the crop (Google, 2007; Azam-Ali and Judge, 2002; VUAT, 2007; FAO, 2004). Heavy soils prevent roots from penetrating downwards and sideways, thus leading to stunted growth and less drought tolerant. Shallow soils, flooded plains, valleys and swampy areas are therefore not recommended for cashew production (NARI, 2007).

Cashew is regarded as "essentially coastal tree" but that is not true. It also grows well at considerable distance from the coast. In East Africa it grows between sea level and 1,000 m in areas of 500 mm rainfall or more (DoA, 2000; Acland, 1977; Keralaagriculture, 2008; VUAT, 2007; QG, 2008). Beyond the altitude of 1,000 m above sea level cashew trees flowering is interfered by low temperatures; and leads to poor cashew nut yield (NARI, 2007).

Cashew is sometimes referred to as a rainforest species. However, the cashew trees that grow in tropical wet forests produce few nuts. Heavy rainfall, evenly distributed throughout the year, is not favourable though the trees may grow and some times set fruits. Cashew needs a climate with a well defined dry season of at least 4 months to produce the best yields. Coincidence of excessive rainfall and high relative humidity with flowering may result in flower abortion or fruit drop and heavy incidence of fungal disease, such as anthracnose (Acland, 1977; Keralaagriculture, 2008; DoA, 2000). Production is much greater in areas with a distinct wet and dry season. According to NARI (2007), for good vegetative growth, flowering and fruit setting, cashew prefers the climate with an average rainfall raging from 800 – 1,600 mm per year and pronounced dry season of 5 to 7 months. Thus, dry spell during flowering and fruit setting ensures better harvest (VUAT, 2007; DCCD, 2008). Cashew can also be grown in areas with rainfall ranging from 600 – 4500 mm per annum (VUAT, 2007; DCCD, 2008).

Cashew is a sun loving tree and does not tolerate excessive shade. It can tolerate temperature of more than 36 °C for a shorter period but the most favourable temperature lies between 24 to 28 °C, which corresponds to the altitude of 0 – 800 m above sea level (DCCD, 2008; NARI, 2007). High temperature (39 - 42°C) during stage of fruit set development causes fruit drop (DCCD, 2008). Cashew is very sensitive to cold, especially in warm winters followed by a freeze (CRFG, 1995). Very low temperatures and frost conditions are not suitable for the crop. (VUAT, 2007; QG, 2008).

2.6 Cashew nut production

Cashew is now the first tree nut crop in the world, since its production surpassed that of almond in 2003 (FAO, 2004). World's total area under the cultivation of cashew is around 33,900 km^2. India ranks first in area utilized for cashew production, though its yields are relatively low. The world's average yield is 916 kg/hectare of land (Wikipedia, 2008).

Tanzania and Guinea-Bissau are the largest producers of cashew nuts in Africa, each accounting for 8 % of the world's production (Business-Times, 2003). Cashew is a good crop for smallholder farmers. In Mozambique cashew is considered by smallholder farmers to be one of their most lucrative or profitable crops. For them, cashew requires few inputs, and harvesting does not coincide with peak labour demands for other food crops (Pagumi, R. personal communication, 2007).

The major cashew producing countries in the world are India, Brazil, Vietnam, Mozambique and Tanzania. Other countries are Sri Lanka, Kenya, Madagascar, Thailand, Malaysia, Indonesia, Nigeria, Senegal, Malawi and Angola (Premier, 2008; FAO, 2008; TFM, 2008). Generally, though cashew is American in origin, the cashew tree is not a primary commercial product in any American country (TFM, 2008).

In 2004, a total of 2,082,101 MT were produced commercially in 32 countries on over 7.5 million acres (FAO, 2004). According to the FAO (2004), Tanzania is one of the top ten producers of cashew nut in world, and of the top ten it is the fifth country (Table 1), contributing 6% of the cashew nuts produced in the world. In 2005, cashew was produced in around 32 countries of the world; and the world production figures of cashew crop, published by the UN's Food and Agriculture Organization (FAO), was around 3.1 million tons per annum.

Table 1. Top ten cashew nut producing countries

S/N	Country	(% of world production)
1	Viet Nam	28
2	India	25
3	Nigeria	10
4	Brazil	8
5	Tanzania	6
6	Indonesia	4
7	Guinea-Bissau	4
8	Cote D'Ivoire	4
9	Mozambique	3
10	Benin	2

Source: FAO, 2004.

With world production in 2000 at about 2 million tonnes of nuts-in-shell and an estimated value in excess of US$2 billion, the cashew industry ranks third in the world production of edible nuts. Cashew kernels are ranked as either the second or third most expensive nut traded in the United States (Azam-Ali and Judge, 2002).

2.7 Cashew nut supply and consumption

The major cashew nut exporters are India, Vietnam and Brazil. The major importing nations are USA, Europe, China, and West Asia. India is the largest processor and exporter; and is the third largest consumer of cashew nuts in the world (Cashew.in, 2006). Collectively, Vietnam, Nigeria, India and Brazil account for more than 90% of all cashew nut kernel exports (Cashew.in, 2006; Wikipedia, 2008).

2.8 Cashew nut production constraints

Generally, worldwide cashews are a product loved by the wealthy nations and provided for by the poor nations (TNF, 2008). Cashew nuts have been called the poor man's crop but a rich man's food. For example, Tanzania loses enormous export value every year by exporting unprocessed cashew nuts. It exports more than 90% of its total cashew production to India in the raw form (Cashew.in, 2006).

The attitude of cashew being a poor man's crop but a rich man's food is commonly practiced worldwide; that small farmers produce the cashew nuts, while large organizations process the product (Rocha, 2006). The World Bank has estimated that at least 97% of world cashew production comes from wild growth and small peasant holdings. At most, systematically planned plantations supply 3% (NutsOnline, 2008).

Africa as a whole accounted for 70 per cent of the global cashew nut production in the period between the 1950s and 1970s. Currently, however, the crop has been adversely affected by lack of high performance plant materials, poor management, attack by parasites and bush fires, as well as the domineering position of oligopolies formed for the most part by Indian companies that generally dictate terms for other producers (SADOCC, 2003).

African production has been constrained by low tree yields, pests, lack of by-product usage, inadequate farmer training and lack of funding. Limited access to credit, abandonment of trees and marketing constraints are the other obstacles

(Shomari, S. H. personal communication, 2004), cited by WAKABI (2004). Some of the problems that face cashew production in Tanzania are similar to the ones that face our neighbouring countries. For instance, in Kenya, the total area under production declined from 38,000 hectares in the late 1980s to 29,950 hectares. The decline was attributed to low prices, poor management of the orchards and other market constraints. However, the main production constraints in Kenya include lack of drought resistant, high yielding and early maturing varieties; along with the presence of powdery mildew disease, red ants and anthracnose in orchards (Onsongo, 2006).

Among the challenges that are facing Tanzania cashew industry is how to improve productivity. To identify or develop planting materials that are high yielding, capable of producing good quality nuts that are acceptable in both agro-ecological sites and markets, is one of the possible solutions. A typical effort was made in Vietnam, which was to identify off-season varieties and novel varieties of crops with comparative advantages (FAO, 2006).

Before 1989, Viet Nam was a net food importer. This was attributed by many reasons (Luat, 2001). One of the reasons was identified in the study carried out in Binh Phuoc and Dak Nong provinces, central highland of Viet Nam, from November 2005 to August 2006. It was realised that farmers decided to sell their cashew nut at harvest because households were not able to fulfil storage and drying cashew nuts and thus reveals their bargaining position. In this case, 45% of transactions done at harvest received the lowest price due to their disadvantaged circumstances. Rationale of selling time was thus one of specific conditions that affected the price of cashew nut (Loan *et. al.,* 2006; NLU and TNU, 2006). After introducing various production strategies the crops yielded better. As the result, Viet Nam has become a cashew nut exporter and is ranked third in world commerce (Luat, 2001) ·

Nevertheless, the biggest constraints found further to limit crop diversification in the country were high cost of inputs and low quality of produce. The study concluded and recommended on much attention that should be paid on techniques that do not require inputs of expensive chemicals (Luat, 2001). A typical lesson within Tanzania could be the use of improved cashew clones.

2.9 Cashew nut picking, yield and postharvest handling

Cashew trees flower and set fruit during the dry season (winter), and nut picking is done within a couple of months (Bradtke, 2007). Depending on variety and daily temperatures during fruit growth, the mature nut with the attached apple falls to the ground from 50 to 90 days after pollination (QG, 2008; DCCD, 2008).

Most cashew trees start bearing fruits in the 3rd or 4th year, and yield starting from 1 kg goes on increasing as the canopy develops and one can expect more that 10 kg of nuts in 8 to 10 years old plant depending on management (DCCD, 2008; VUAT, 2008). In dry areas, like Tanzania, flowering occurs in dry season, and fruits mature in 2 – 3 months (Duke, 1983). Economic bearing in cashew commences after 3rd year of planting depending on management. (DCCD, 2008; VUAT, 2008).

Trees generally give full yields of 30 kg of nuts after 8 - 10 years. They then continue to yield for about 30 years (FAO, 2008). Under good conditions up to 70 kg/tree/year can be produced. However, under poor conditions it can be as little as 8 – 10 kg/tree/year. A well maintained field is expected to produce 1000 kg/ha (NARI, 2007). However, yields of up to 7000 – 9000 kg/ha of cashews are possible, giving 150 - 300 kg shelled nuts per hectare (FAO, 2008). Although the cashew tree is capable of living for 50 to 60 years, most trees produce nuts for about 15 to 20 years (Azam-Ali and Judge, 2002; FAO, 2004).

Harvesting of cashew nut is time consuming and labour intensive. It is done by reaping the nuts that have dropped to the ground after maturity (Ohler, 1979). Ripe cashews can be picked from the tree but it is recommended that they are allowed to fall to the ground before they are gathered. This is to ensure that no unripe fruits are harvested (FAO, 2008). If fruits are picked from the trees, the cashew apple will be ripe, but the kernel will still be immature (Azam-Ali and Judge, 2002). When the nuts are collected the cashew apple remains attached to the nut. This is removed by hand with a twisting action. Any pieces of the apple remaining on the nut are also removed (Acland, 1977).

A maximum of 50 kg can be harvested per person-day, but in several cases this quantity cannot be attained. For instance, where humidity of the air or soil is higher, and especially when the early rains start before harvest is over, nuts need to be picked every day to avoid deterioration. Under these conditions, harvesting becomes expensive, as there will not be enough nuts to harvest sufficient quantities per day (Ohler, 1979).

For the nuts to be easily traced, the surface under the tree has to be free from weeds. In some places, the whole area under the tree is swept free of dry leaves. Where many nuts fall together, much less time is required for walking in search of them. A very limited number of nuts fall at the beginning of the production season. Peak harvest is gradually attained and later on production slowly declines (Ohler, 1979; VUAT, 2008).

After harvesting, the cashew apple keeps for only 24 hours before the soft fruit deteriorates. The cashew apples are not commercially important since they spoil quickly, though they are sometimes consumed raw (TNF, 2008). Since the apples are highly perishable, frequent collection must be made if they are to be utilized (FAO, 2004).

The nuts rot quickly; therefore, it is recommended that during fine weather, harvesting should not be allowed to lapse for periods of more than one week. In wet weather nuts should be collected daily (FAO, 2008). If nuts are left on the ground for longer than a week the seed coats become brown, rotten and stimulate nut germination (FAO, 2004). Nuts germinate within 4 days when lying on wet soil (DoA, 2000; AgricultureInformation.com, 2008). Nuts can be dried in the sun for 2 to 3 days on cement floor and can be stored in gunny bags (DCCD, 2008). After drying, the seeds can be stored in bags or bulk for a few days before processing

(FAO, 2008). Dried nuts can be stored for about 2 years at room temperature after reaching moisture contents of 5 - 10% (FAO, 2004). For export or packing purpose moisture content should not exceed 5% calculated in mass (JAC, 2007). Nuts are separated by size before roasting to ensure uniformity of the roasting process. After roasting, nuts are shelled either by hand or machines (FAO, 2004).

2.10 Cashew nut picking duration

Cashew harvesting takes 24 four weeks to complete the season, in which 90% of the crop is harvested from 11th to 13th week. In dry season cashew nut picking is done at least three days per week, but in rain days it is done daily (NARI, 2006). However, this duration depends on the cultivars. Different cashew genotypes may have different nut picking durations (Masawe, P. personal communication, 2006).

Harvesting periods in East Africa starts in August and lasts until March. Peak harvesting is between October and December (FAO, 2008). In Tanzania, harvesting season in the Coast region is from October to January (Premier, 2008). However, some cashew trees may produce an additional light crop beyond these periods (Woodroof, 1979; FAO, 2008).

2.11 Cashew nut quality

Worldwide, cashews are traded as cashew kernels in several grades, based on the size, colour and other quality parameters of cashew (cashew.in, 2006). In Tanzania, cashew nuts are graded by physical assessment, where by the raw nuts are graded in terms of colour. Two grades namely, standard grade (SG) and under grade (UG) are popular in this aspect (NARI, 2007). The SG nut should be grey or pale brown, and they should neither be wrinkled nor spotted. This can be achieved from healthy fully matured and well dried nuts (about 12% MC). On the other hand, the UG nuts are well matured nuts and dry, but lack desirable colour. However, cutting test to establish the grades scientifically is essential (NARI, 2007).

The importance of nut weight, kernel weight and percentage kernel is realised when conducting cutting test. Small size nuts normally fetch low prices, and they are uneconomical during processing. This is because, several cutting times are needed to finish a given unit weight of small nuts as compared to the same weight of large nuts (Masawe, personal communication, 2005). In addition, depreciation of tools or equipment is obviously higher with a batch of small nuts than with large ones. Moreover, the processing machines are designed for standard sizes of the nuts. The nut with at least 6 g, with kernels weighing at least 1.5 g and percentage kernel out-turn of at least 20 % are acceptable (CRP, 2004/05; CRP 2005/06, Anonymous). However, the cashew kernels are difficult to extract whole compared to other tree nuts (Wikipedia, 2008; FAO, 2004).

Grading by size is important as it helps in achieving uniformly roasted or heating nuts as a preparation for nut-cutting in order to extract them from the cashew nut shells. According to TNF (2008), Woodroof (1979) and FAO (2008) some kernels get scorched because they become overheated near the bottom of the pile. Moreover, according to Joyce Kayombo (personal communication, 2008), most of the over heated cashew nut kernels break into butt pieces when they are removed from the cashew nut shells. Extreme differences in nut sizes (say mixing together nuts with less than 6 g and the ones with 10 g or more), may possibly lead to over roasting of the small ones or under heating the large ones. These kernels become second and third grades in quality (TNF, 2008). However, in Tanzania, chemical grading is not practiced (Cashew.in, 2006; Nandi, 2005; QG, 2008; DCCD, 2008).

2.12 Genotype-environment interaction

Genotype-environment (GE) interaction occurs when two or more genotypes are compared in different environments and found to differ in their responses. Agricultural research and development applied to crops has three components: (a) the breeding or genetic (G) component, (b) husbandry, agronomic or environmental (E) component and (c) the interaction (GE). Successful plant breeding with or without interaction lowers cost per unit supply. Innovating farmers will profit transiently, but as the new variety spreads, market forces will tend to produce a new equilibrium in which economic benefits are distributed to consumers collectively in the form of lower prices (Simonds and Smartt, 1999).

The crop breeding objectives can therefore be classified into broadly yield and quality (plus few oddments or leftovers). Yield is promoted by enhanced biomass, of which disease instance is an important component, and an improved partition (more products less waste. Quality is fitness for purpose and must be distinguished from condition (the product of environmental circumstances out with the breeder's control). Quality factors are very various and essayed by four broad categories of test, depending upon crop and purpose: organoleptic (subjective taste, smell, texture, appearance), chemical, mechanical and biological. Given the uncertainties, biological, agricultural and economic, decisions about objectives are never simple (Simonds and Smartt, 1999).

Taking view of the uncertainties, the breeder, therefore needs to recognize the existence of GE effects and decide whether he/she will aim at widely adapted varieties or will select for adaptation to sub-environments within the relevant area. Experience of the past and present varieties will provide at least some guidance. The existence of GE interaction is shown by a significant item in an analysis of variance, for example, sites × verities or years × verities or years × site × varieties. Formal statistical trials are thus normally necessary for detection. However, an analysis of variance can only detect GE effects; it tells us nothing about them (Simonds and Smartt, 1999).

Therefore, an understanding of the causes of genotype × environment interaction can help identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation (Yan and Hunt, 2000). For example, a study of genotype × environment interactions effects on the yield of 10 early-maturing genotypes of pigeon pea (*Cajanus cajan* L. Millsp.), in a total of seven environments spread over five regions of Kenya between 1987 and 1988 noted that the best genotype in one environment is not always so in other environments (Wamatu and Thomas, 2002). Cultivar, environment, time of harvest and their interactions has also shown significant effects on sugarcane yield and quality (Gilbert *et al.*; 2007).

The understanding of casual relationship among yield components and their effect on yield can be achieved by carrying out path coefficient analysis. Path coefficient analysis is a standardized partial regression coefficient, which measures the direct influence of one variable upon another and it permits separation of the correlation coefficients into direct (independent) and indirect (dependent) effects. Path coefficient analysis differs from simple correlation in fact that: simple correlation coefficient measures mutual association without regard to causation while the path coefficient analysis specifies the causes and measure their relative importance (Reuben, *et al*., 1998). Therefore, the path coefficient analysis is more informative and useful in determining the nature and relationships between yield and yield influencing factors than simple correlation coefficients. However, according to Singh and Chaudhary (1977), there are situations in which attention has to be paid in selecting desirable effects: (a) If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects seem to be the reason for correction. In such situations, the causal factors must be considered simultaneously; and (b) the correlation coefficient may have negative value, but its direct effect is positive and high; under such circumstances, restrictions are to be imposed to nullify the undesirable indirect effect to make use of direct effect (Singh and Chaudhary, 1977).

Nevertheless, when conducting genotype-environment interactions, more emphasis should be placed on sampling a greater number of locations than on the testing of genotype ability within locations. This would improve the chances of obtaining both broadly and specifically adapted crop varieties (Mirzawan *et al*., 1993). Moreover, the study of genotype-environment interaction requires understanding of the importance of different variables in the interaction. For example, the major component of interaction have to be identified as a contrast, say between early and late cultivars; while a minor component can be cultivars that perform relatively well in the worst environment and relatively badly in the best environment (Eeuwijk and Elgersma, 2008).

It is suggested that in locations where genotype-environment interaction for yield frequently causes re-ranking across environments, genotypes with the least contribution to the interaction sum of squares are likely to be most productive. On the whole, this supports the contention (opinion or claim) that breeding under sole-crop conditions has the potential to produce cultivars effective under intercropping conditions (Padi, 2007).

A genotype is considered stable when its performance across environments does not deviate from the average performance of a group of standard genotypes (Gonçalves *et al.*, 2003). That is why, whenever new varieties are proposed for commercial release, information on genotype-environment interactions and stability, clearly indicating their specific and/or general adaptations, are made available to the user (Gonçalves *et al.*, 2003)

In Tanzania, selection criterion of cashew planting materials used in the past years was based on nut characteristics, and particularly on the ability of the tree to produce reasonable yield over several years. This was because before 1970s diseases and insect pest incidences were not reported (Martin *et al.*, 1997). Studies in North America and Europe provide strong evidence that global climate change has already caused changes in the timing of biological events (Groom *et al.*, 2006). Tanzania has also been experiencing weather changes, which has sometimes resulted in delayed cashew flowering and nut development, and in turn results into coinciding of nut picking with rains. For instance, regardless the fungicides application, in 2008, cashew performance against powdery mildew was generally reported to be poor, in most cashew growing areas in South-Eastern Tanzania; though some genotypes in some locations have shown a relatively good performance. This was probably associated with prolonged low temperatures during flowering and nut setting (Sijaona, M. personal communication, 2008).

CHAPTER THREE

3.0 METHODOLOGY

During laboratory work, weights were taken using electronic balance, as most readings were in grams.

3.1 Determination of cashew nut picking duration

Determination of cashew nut picking duration was conducted on the seven cashew clones vegetatively propagated by grafting method and planted in 1990/91 season in the three sites. Harvesting was carried out per clone on tree basis.

Number of days that were taken to complete nut picking was determined by noting the first and last date of nut picking for each clone; and then finding the interval between the two dates. The cashew nut picking started when there were economically sufficient mature nuts dropped on ground and it ended when the nuts were economically too insufficient to continue picking. The decisions of when to start and end harvesting were typical of the farmers' practices.

3.2 Cashew nut yield determination

Total yield for each clone within the time taken to complete the cashew nut picking was recorded daily on tree basis, using weighing balance. Canopy diameter of each cashew tree was measured using tape a measure at the end of harvesting season, but before the trees enter into vegetative phase. The canopy diameter was used to determine canopy ground cover area, which was used to assess the yield per unit area (kg/ha) for each clone.

3.3 Determination of nut weight

A randomly sampled 100 g of nuts from each cashew tree was taken. Number of nuts contained in the 100 g was determined. To determine the nut weight, 100 g were divided by the number of nuts contained in the 100 g sample.

3.4 Determination of kernel weight

To determine kernel weight, the 100 g of nuts measured during nut weight determination were dissected (opened up) longitudinally to remove out the kernels. The removed kernels were weighed. The weight of the kernels obtained was divided by the number of nuts contained in the 100 g sample.

3.5 Determination of percentage kernel out-turn

Percentage kernel out-turns, simply refers to what proportion of useful kernels obtained in a given unit of raw nuts. This process involved opening up of the nuts and removing out the kernels from shells and measuring their weights. Diseased, spotted, wrinkled and void nuts were considered not useful. A randomly picked sample of 100 g raw nuts from each tree was taken to determine percentage kernel out-turns. The raw nuts were opened up longitudinally to remove out kernels. The percentage kernel out-turns were determined by measuring the weight of useful kernels removed from the raw nut samples and dividing it by weight of the raw nuts, and then multiplied by one hundred.

3.6 Determination of nut length

To determine nut length, 10 nuts from each cashew tree were randomly sampled on weekly basis from a thoroughly mixed lot. Nut length was determined by measuring the distance from nut base to apex using a veneer calliper. The average nut length was determined by dividing the total nut length of the 10 sampled nuts by 10. The nut length used in statistical analysis was obtained by determining the means of the weekly averages.

3.7 Determination of nut thickness

Ten nuts from each cashew tree were randomly sampled on weekly basis from a thoroughly mixed lot. Nut thickness was determined by measuring the maximum distance between nut flanks using veneer calliper. The average thickness was determined by dividing the total thickness of the 10 sampled nuts by 10. The nut thickness was the mean calculated from the weekly averages of the nut thickness.

3.8 Determination of nut boiling time

Half a kilogram of randomly picked cashew nuts from each cashew tree was immersed in boiling water and let continue boiling. While immersing the seeds, the time was recorded. After 15 minutes, some nuts were randomly taken out of the boiling water and finger pressed at its suture, to test whether they were well boiled or not. This exercise was repeated after every 5 min. Ready boiled nuts opened up their sutures easily. When such required boiling was reached, the time was recorded. The nut boiling time was determined by subtracting the time recorded when reaching the required boiling from the time recorded during immersing of the nuts in the boiling water.

3.9 Nut cutting and kernels preparation for nutritional quality determination

The ready boiled nut samples were removed from the boiling water and allowed to cool for 12 hrs before nut cutting and removal of the kernel was carried out. After the cooling process was complete, the nuts were gently beaten with wooden materials (sticks) along the nut suture to open up the shells. After opening the shells the kernels were removed out with their testa. The kernel testa were peeled with knives and packed in 50 g lots ready for chemical analysis.

3.10 Fat content determination

Fat content was determined by *Soxhlet Continuous Extraction* method. Kernel samples each weighing 50 g was milled and a fine powder was separated using a 1 mm sieve. Samples (3 g each) of the powder were put into a thimble. The thimble containing the weighed sample of kernel powder was then put in weighed soxtec cup, which was oven dried before for 2 hours and cooled in desiccators for ½ hr. Forty millilitres of solvent (petroleum ether) was added into the cups. The cups with the contents were then placed in the soxtec machine and boiled for 1 hour at 107 °C. The cooling unit of soxtec machine was set at about 14 °C to cool the solvent. Thereafter, the remaining solution in the cups was placed in oven set at 100 °C for ½ hr to evaporate unwanted materials such as the traces of solvent and water. It was then removed and cooled in desiccators for ½ hr. The weight of the cup with fat was recorded. Net weight of the fat was obtained by subtracting the weight of the solution (fat) with cup from weight of cup with kernel powder. Percentage fat content in the sample was calculated using the formula:

$$\% \text{ Fat content } = \left(\frac{\text{weight of fat with cup}}{\text{weight of cup with kernel powder}}\right) \times 100$$

3.11 Protein content determination

Protein content determination was carried out by *Kjeldalh* method. One gram sample was placed in a digestion tube. Half tea spoon of catalyst was made up of potassium sulphate, copper sulphate and selenium powder mixed in a ratio of 10:1:0.1 respectively, was introduced into the digestion cup containing the kernel sample. This was followed by 6 ml sulphuric acid. The samples were then placed in digestion chamber and heated for one hour. After one hour the samples were allowed to cool. Then, a fractional distillation was carried out to separate ammonia from the digested contents. The ammonia was collected in a conical flack containing 25 ml of boric acid. The boric acid was used to trap up the gas into the form of ammonium borate. The ammonia solution (ammonium borate) was titrated against hydrochloric acid to obtain the actual content of ammonia. Amount of nitrogen (N) was determined from the ammonia, which was then used to calculate the actual protein content in the sample using the following formulae:

$$\% \text{ N} = \left(\frac{14.01 \times (\text{Titre} - \text{Blank}) \times \text{Conc. HCl}}{5.00 \times 10}\right) \times 100$$

But, CP = % N × factor

Where, N = nitrogen

Titre and blank = volume in ml

Conc. HCl = concentrated hydrochloric acid

CP = crude protein

Factor = 6.25

3.12 Mineral determination

To analyse mineral contents, samples from kernel powder (each 5 g) were put in crucibles and burned in blast furnace at 500 °C for 3 hours to destroy organic matter. After burning, ashes were allowed to cool. Then, each sample was dissolved in 10 ml of dilute hydrochloric acid (1:1 = $HCl:H_2O$ ratio = 6N) and stirred thoroughly. The dissolved content was filtered with a filter paper placed in filter funnel. The filtrate was collected in a conical flask, and then transferred into 100 ml volumetric flask. Distilled water was added into the filtrate to make up 100 ml volume of the filtrate ready for mineral determination.

3.12.1 Phosphorus determination

To determine phosphorus content, 25 ml of the filtrate was drawn into 50 ml volumetric flask using a pipette. Distilled water (10 ml) was added into the 25 ml filtrate. To fix colour of the solution, 4 ml of ascorbic acid were added after addition of the 10 ml of distilled water, which was followed by addition of more distilled water to make up 50 ml. The solutions were thoroughly shaken and left to stand for 20 min. Within the 20 min, a fixed blue colour was attained. The more intense the colours were the higher the phosphorus concentrations. These were determined by measuring absorbance of blue coloured solution using U-Visible Spectrometer set at the wave length of 882.0 nm.

3.12.2 Determination of calcium, magnesium, potassium and sodium

To determine calcium, magnesium, potassium and sodium, the filtrate was diluted 10 times with distilled water as their levels in food are normally high. Calcium and magnesium concentrations were measured using atomic absorption spectrum at wave lengths 422.7 nm and 285.2 nm, respectively. Concentrations of potassium and sodium were determined using flame photometer at 766.5 nm and 589.0 nm, respectively.

3.12.3 Determination of iron, zinc and copper

Atomic absorption spectrum was also used to determine concentrations of iron, zinc and copper. However, since their levels are normally very low, they were determined just after making up the 100 ml solution by adding distilled water into the filtrate collected from the dissolved ash. The atomic absorption spectrum was set at the wave lengths of 248.3 nm (for iron), 324.8 nm (for copper) and 213.9 nm (for zinc).

3. 13 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD). Two factors, namely sites or locations (environments) and clones were used. These were arranged in a split plot experiment; in which three sites (Naliendele, Nanyanga and Nyangao) were the main-plot treatments, where as seven clones (AZA17, AC4/285, AZA2, AC10/220, AC14, AC4 and AC10) planted in four replications were the sub-plot treatments. A plot was composed of three trees planted in rectangular pattern at a spacing of 20.8 × 12.0 × 10.4 m.

3.14 Data collection

The following data were collected:

- Number of days to complete nut picking
- Total yield for each clone within the time taken to complete nut picking (kg)
- Canopy ground cover area for each clone (m^2)
- Nut weight (g)
- Kernel weight (g)
- Percentage kernel out-turn
- Nut length (cm)
- Nut thickness (cm)
- Nut boiling time (min)
- Fat content (%)
- Protein (%)
- Phosphorus (%)
- Calcium (mg/kg)
- Iron (mg/kg)
- Zinc (mg/kg)
- Copper (mg/kg)
- Magnesium (%)
- Potassium (%)
- Sodium (mg/kg)

3.15 Data analysis

The data collected from this study were subjected to the analysis of variance for the Complete Randomized Block Design under the split plot arrangement using the statistical model shown in Appendix 2. Data analysis was carried out by means of Statistical Analysis System (SAS) package. Treatment means were compared using Duncan's Multiple Range Test. Moreover, path coefficient analysis was performed to determine the effects of the following six selected factors assumed to be important in cashew nut yield:

- Altitude
- Nut length
- Kernel weight
- Nut weight
- Yield/day and
- Nut picking duration.

The path coefficients were determined by solving the following simultaneous equations arranged in matrix notation.

$$r_{16} = P_{16} + r_{12}P_{26} + r_{13}P_{36} + r_{14}P_{46} + r_{15}P_{56}$$

$$r_{26} = P_{26} + r_{21}P_{16} + r_{23}P_{36} + r_{24}P_{46} + r_{25}P_{56}$$

$$r_{36} = P_{36} + r_{31}P_{16} + r_{32}P_{26} + r_{34}P_{46} + r_{35}P_{56}$$

$$r_{46} = P_{46} + r_{41}P_{16} + r_{42}P_{26} + r_{43}P_{36} + r_{45}P_{56}$$

$$r_{56} = P_{56} + r_{51}P_{16} + r_{52}P_{26} + r_{53}P_{36} + r_{54}P_{46}$$

The residual, P_{X6} was computed from the following equation:

$$I = P^2_{X6} + P^2_{26}\, P^2_{36} + P^2_{46} + P^2_{56} + 2P_{16}\, r_{12}P_{26} + 2P_{16}\, r_{13}P_{36} + 2P_{16}\, r_{14}P_{46} + 2P_{16}\, r_{15}P_{56}$$
$$+ 2P_{26}\, r_{23}P_{36} + 2P_{26}\, r_{24}P_{46} + 2P_{26}\, r_{25}P_{56} + 2P_{36}r_{34}P_{46} + 2P_{36}\, r_{35}P_{56} + 2P_{46}\, r_{45}P_{56}$$

Where, r_{ij} = simple correlation coefficients for measuring the mutual association of the two variables

P_{ij} = path coefficients for measuring direct effects of the variables on yield

$r_{ij}P_{ij}$ = indirect effects of variables upon another via other variables

P_X = the residual effect in the path analysis model; i and j = (1, 2, 3, ..., 6)

CHAPTER FOUR

4.0 RESULTS

4.1 Cashew nut picking duration based on time length

The results for cashew nut picking duration based on time length are shown in Table 2. Significant variations ($P \leq 0.05$) in cashew nut picking duration were observed among clones within and across locations. While clone AZA17 gave the shortest mean cashew nut picking duration (34 days) at Naliendele, the longest mean cashew nut picking duration (74 days) was recorded on AC14. At Nanyanga, the clone AZA17 also recorded the shortest mean cashew nut picking duration (51 days), while clones AC4 and AC14 had the longest time of 62 days. Furthermore, the clone AZA17 showed superiority over other clones by giving the shortest mean cashew nut picking duration of 55 days at Nyangao, while at that site AC10 gave the longest mean cashew nut picking duration (72 days).

Across the three sites, the mean cashew nut picking duration ranged from 47 to 67 days, recorded on AZA17 and AC14, respectively. Overall mean cashew nut picking duration was 56 days. Based on locations, the shortest overall mean of cashew nut picking duration (48 days) was found at Naliendele. Nyangao site gave the longest overall mean of cashew nut picking duration (62 days). The overall mean of cashew nut picking duration at Nanyanga was 57 days.

Table 2. Means for cashew nut picking duration, yield per day and yield per season at Naliendele, Nanyanga and Nyangao

Clone	Cashew nut picking duration (days)				Cashew nut yield per day (kg/ha)				Cashew nut yield per season (kg/ha)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AC14	74^{a}	62^{a}	64^{ab}	67^{a}	43.5^{e}	31.5^{bc}	32.7^{c}	35.9^{c}	3164.8^{cd}	1942.6^{cd}	2084.8^{c}	2397.4^{d}
AC10/220	53^{b}	55^{ab}	63^{ab}	57^{cb}	67.4^{cd}	23.5^{c}	28.6^{c}	39.8^{c}	3433.8^{bcd}	1289.8^{e}	1841.5^{c}	2188.4^{e}
AC10	50^{b}	57^{ab}	72^{a}	60^{b}	55.2^{de}	31.0^{bc}	27.2^{c}	37.8^{c}	2691.2^{d}	1704.0^{de}	1954.0^{c}	2116.4^{e}
AZA2	47^{bc}	53^{ab}	59^{b}	53^{c}	80.8^{bc}	40.1^{ab}	49.3^{ab}	56.7^{b}	3800.7^{abc}	2105.0^{bcd}	2850.1^{ab}	2918.6^{c}
AC4/285	41^{cd}	58^{ab}	61^{b}	53^{c}	116.3^{a}	44.5^{a}	55.6^{a}	72.1^{a}	4604.9^{a}	2653.6^{ab}	3278.2^{a}	3512.2^{a}
AC4	36^{d}	62^{a}	61^{b}	53^{c}	116.2^{a}	44.4^{a}	50.6^{ab}	70.4^{a}	4135.0^{ab}	2762.0^{a}	3020.9^{ab}	3306.0^{b}
AZA17	34^{d}	51^{b}	55^{b}	47^{d}	90.5^{b}	50.0^{a}	44.4^{b}	61.6^{b}	2879.3^{d}	2446.3^{abc}	2436.4^{bc}	2587.3^{d}
Overall mean	48	57	62	56	81.4	37.9	41.2	53.5	3530.0	2129.0	2495.1	2718.0
s.e. (±)	2.73	3.06	3.27	3.02	7.30	3.37	3.54	3.26	293.76	214.32	230.63	72.38
c.v. (%)	18.4	14.6	14.6	10.8	28.6	24.5	24.1	30.2	26.7	27.5	25.8	26.1

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

4.2 Cashew nut yield per day

Significant variations ($P \leq 0.05$) in cashew nut yield per day were observed among clones (Table 2). The best clone which was found to produce the largest mean quantity of cashew nuts per day at Naliendele was AC4/285. Its yield (116.3 kg/ha per day) varied significantly ($P \leq 0.05$) from AC14, which gave the least mean yield per day (43.5 kg/ha). Performance of cashew nut yield per day at Nanyanga showed the mean yield that ranged from 23.5 to 50.0 kg/ha harvested on AC10/220 and AZA17, respectively. The clone AC4/285 exhibited superior performance in cashew nut yield per day at Nyangao, where it yielded 55.6 kg/ha per day compared to the poorest yielding clone AC10 which produced 27.2 kg/ha per day.

Overall mean yields across the three locations varied significantly ($P \leq 0.05$) from 35.9 to 72.1 kg/ha per day, recorded on AC14 and AC4/285, respectively, with an overall mean of 53.5 kg/ha per day. Naliendele was the leading site in overall mean yield per day (81.4 kg/ha) while Nanyanga site showed the lowest overall mean yield (37.9 kg/ha per day). The seven clones grown at Nyangao produced an overall mean yield of 41.2 kg/ha per day.

4.3 Cashew nut yield per season

Table 2 presents the means for cashew nut yield per season at Naliendele, Nanyanga and Nyangao. The best yield performance at Naliendele was recorded on AC4/285, where it produced the mean yield of 4604.9 kg/ha, while the lowest mean cashew nut yield per season (2691.2 kg/ha) was recorded on AC10. With respect to mean yield per season at Nanyanga, the clone which outperformed all other treatments was AC4. It produced 2762.0 kg/ha. The least mean yield (1289.8 kg/ha) was produced by AC10/220. Significant variability ($P \leq 0.05$) on cashew nut yield among clones were also observed at Nyangao site, where AC4/285 gave the highest yield (3278.2 kg/ha), contrary to AC10/220 which produced the least yield of 1841.5 kg/ha.

The minimum and maximum mean yields of the seven clones across the three locations were 2116.4 and 3512.2 kg/ha for AC10 and AC4/285, respectively with overall mean of 2718.0 kg/ha. The highest overall mean of cashew nut yield per season (3530.0 kg/ha) was obtained at Naliendele, while Nanyanga produced the lowest overall mean yield (2129.0 kg/ha).

4.4 Cashew nut picking duration based on time of attaining the highest yield proportion

Based on the time of attaining the highest yield proportion, the cashew nut picking duration at Naliendele differed significantly ($P \leq 0.05$) among clones (Fig. 2). The harvesting was carried out between 18th September and 21st December 2007. Mid harvesting season was reached on 3rd November, 2007. Cashew clone AC4 produced 97 % of the mean nut yield before the mid season, contrarily to AZA17 which attained 76 % of its mean yield between 4th and 23rd, November 2007.

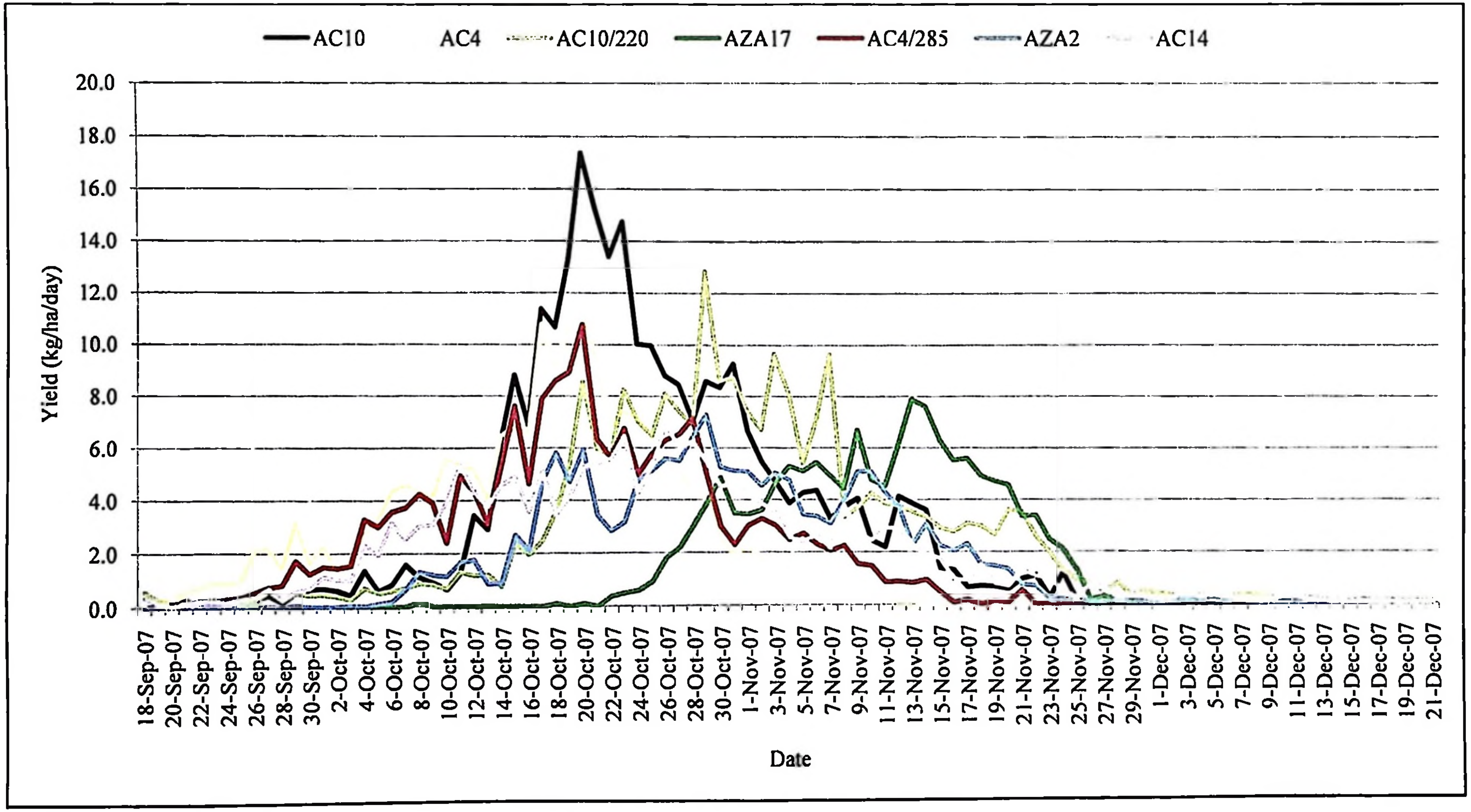


Figure 2. Nut picking duration of seven cashew clones at Naliendele

At Nanyanga cashew nut harvesting was performed between 5th September and 16th December 2007 (Fig. 3). However, significant variations ($P \leq 0.05$) in nut picking duration were observed among clones. By 25th October 2007, the harvesting season was halfway. Clone AC4 showed superiority in early yielding over others by producing 67 % of the mean yield before 25th October 2007. On the other hand, AC10/220 was revealed as a late maturing clone, of which its 91 % mean nut yield was collected between 12th and 30th November, 2007.

The cashew nut picking duration also differed markedly ($P \leq 0.05$) among clones at Nyangao (Fig. 4). At this location, cashew nut harvesting took place from 17th September to 2nd December 2007. The best clone in giving the highest yields early in the season was AC4/285. This clone yielded 89 % of cashew nuts before 23rd October 2007, which was the middle of the harvesting seasons. The investigation further identified AZA2 as late maturing clone. At this location, 84 % of the cashew nuts picked on AZA2 were recorded between 27th October and 24th November, 2007.

The other observation found in this study was that, while Naliendele and Nanyanga sites exhibited overall sharp distinct peaks of the cashew nut harvesting, Nyangao site did not; it rather showed several peaks, which were almost evenly distributed from the beginning to the end of the season (Fig. 2, 3 and 4).

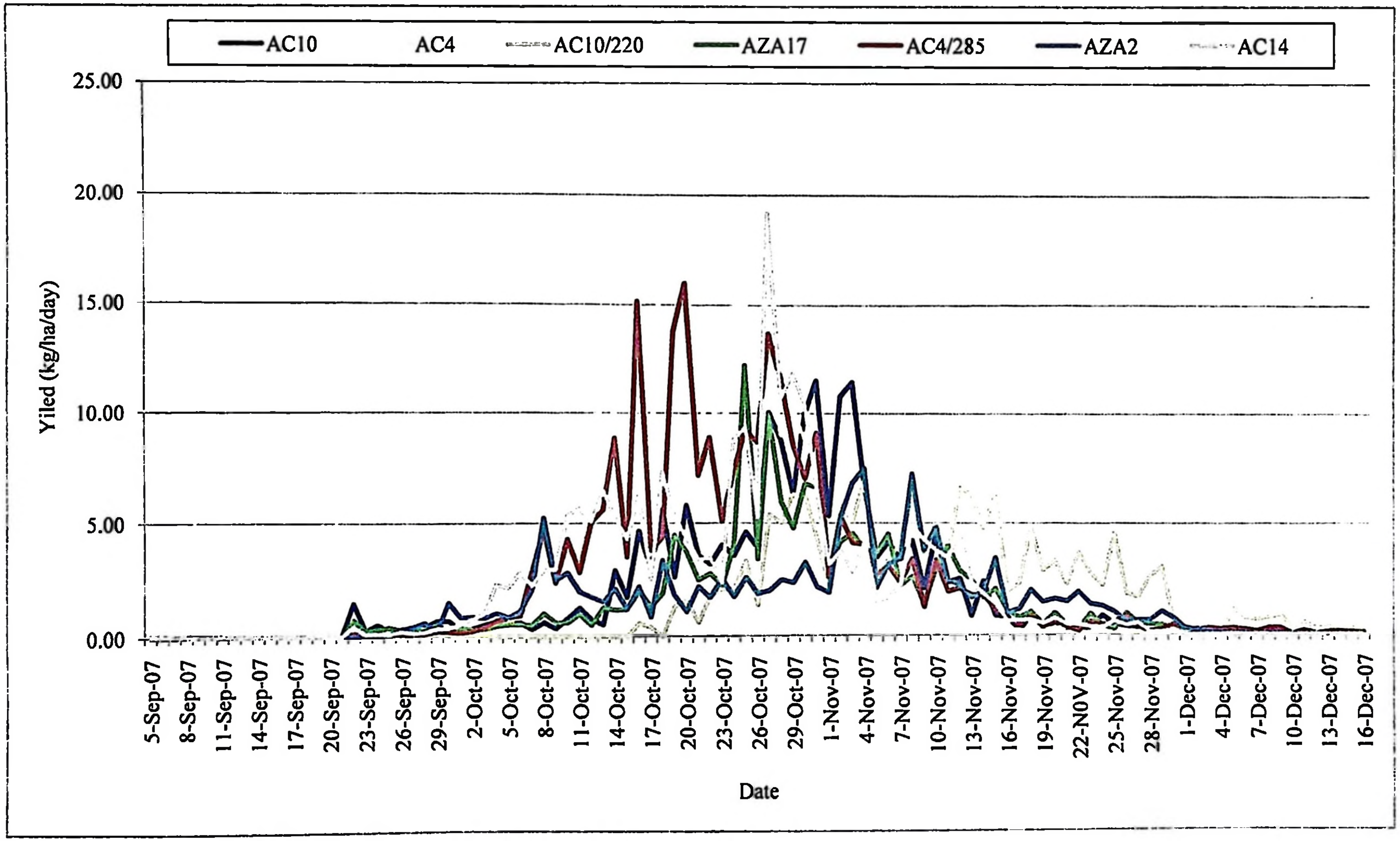


Figure 3. Nut picking duration of seven cashew clones at Nanyanga

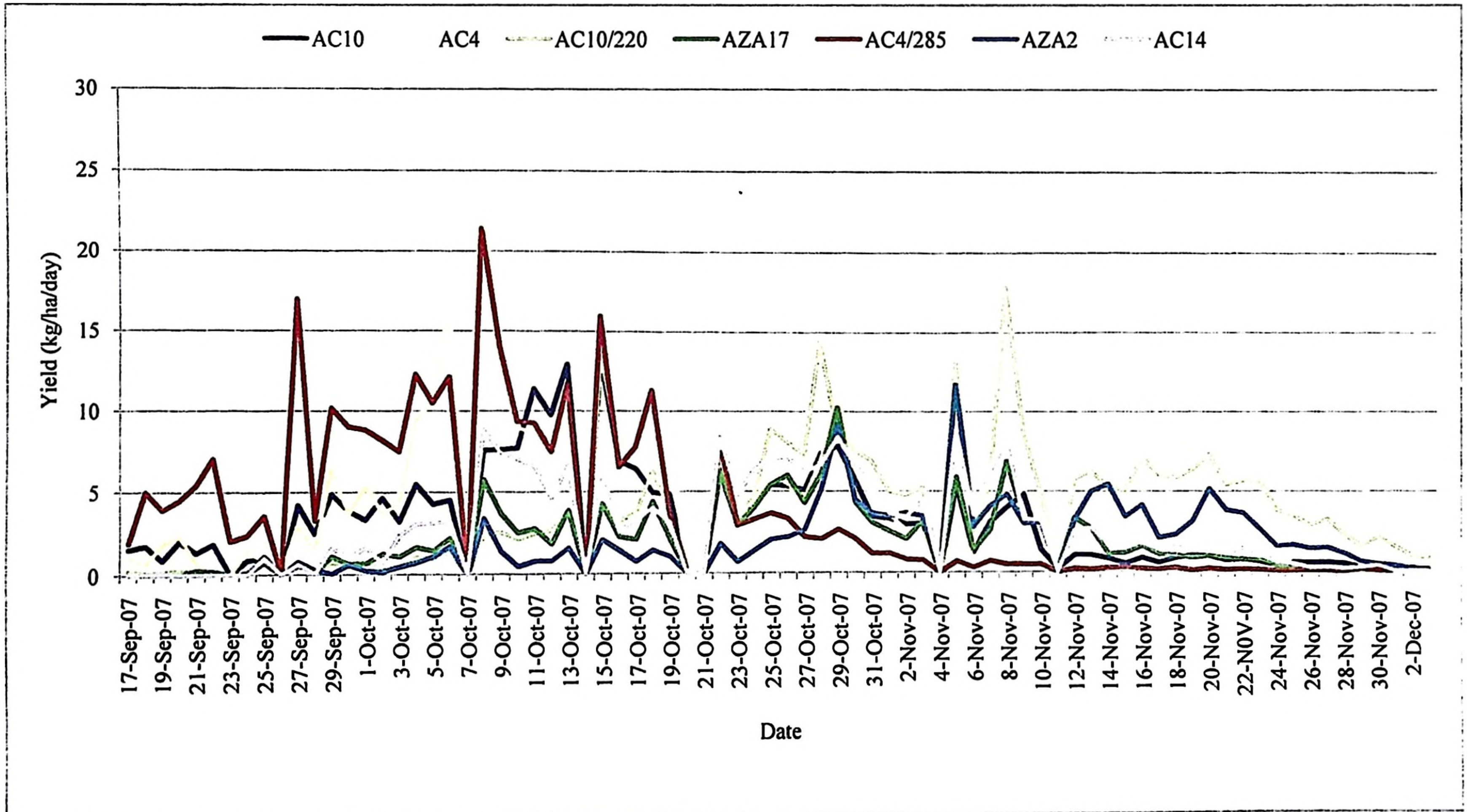


Figure 4. Nut picking duration of seven cashew clones at Nyangao

4.5 Physical nut quality

4.5.1 Nut weight

Table 3 presents the results for mean nut weight. Significant variations ($P \leq 0.05$) were observed among clones. At Naliendele, AC10/220 outperformed other clones by producing nuts weighing 8.8 g. The lowest mean nut weight (6.2 g) was recorded on AC4/285. The clone AC10/220 also produced the heaviest nuts (9.0 g) at Nanyanga, while clone AZA17 indicated inferior mean nut weight of 5.7 g. Analysis of nuts from Nyangao site found a minimum and maximum mean nut weights on AZA17 and AC10 with respectively values of 6.6 and 11.0 g.

On average, AC10 showed the best performance across the three locations by giving the highest mean nut weight (9.3 g). The least mean nut weight (6.3 g) was measured on AZA17. The overall mean nut weight across the three locations was 7.8 g. On the other hand, while cashew nuts harvested at Nyangao showed the highest overall mean weight (8.5 g), nuts from Nanyanga measured the least overall mean weight (7.4 g). Naliendele site recorded the overall mean nut weight of 7.5 g.

Table 3. Means for cashew nut weight, kernel weight and percentage kernel out-turn at Naliendele, Nanyanga and Nyangao

Clone	Nut weight (g)				Kernel weight (g)				Percentage kernel out-turn (%)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AC10/220	8.8^{a}	9.0^{a}	8.9^{b}	8.9^{b}	2.3^{b}	2.6^{a}	2.4^{bc}	2.4^{b}	30.2^{c}	29.6^{c}	27.7^{d}	29.2^{c}
AC10	8.7^{a}	8.3^{ab}	11.0^{a}	9.3^{a}	2.5^{ab}	2.6^{a}	2.7^{a}	2.6^{a}	29.0^{c}	30.6^{bc}	28.8^{cd}	29.5^{c}
AC4	8.4^{a}	8.3^{b}	10.3^{a}	9.0^{ab}	2.7^{a}	2.3^{b}	2.6^{ab}	2.5^{a}	33.1^{b}	31.6^{abc}	29.8^{bc}	31.5^{b}
AC14	7.2^{b}	7.8^{b}	8.4^{b}	7.8^{c}	2.4^{b}	2.3^{b}	2.2^{c}	2.3^{c}	32.4^{b}	32.4^{ab}	29.9^{bc}	31.6^{b}
AZA17	6.5^{c}	5.7^{d}	6.6^{c}	6.3^{e}	2.0^{c}	1.9^{c}	2.0^{d}	2.0^{de}	33.1^{b}	33.3^{a}	31.4^{ab}	32.6^{a}
AZA2	6.4^{c}	6.7^{c}	7.5^{c}	6.9^{d}	1.9^{c}	1.9^{c}	1.9^{d}	1.9e	29.4^{c}	30.2^{bc}	28.3^{cd}	29.3^{c}
AC4/285	6.2^{c}	6.3^{cd}	7.1^{c}	6.5^{de}	2.0^{c}	1.8^{c}	2.3^{c}	2.0^{d}	34.5^{a}	32.4^{ab}	32.1^{a}	33.0^{a}
Overall mean	7.5	7.4	8.5	7.8	2.3	2.2	2.3	2.3	31.7	31.4	29.7	30.9
s.e. (±)	0.20	0.23	0.31	0.14	0.08	0.10	0.07	0.05	0.44	0.79	0.61	0.35
c.v. (%)	8.8	8.4	10.1	9.4	10.96	12.3	9.0	12.3	4.4	6.9	5.8	5.9

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

4.5.2 Kernel weight

Mean kernel weights varied significantly ($P \leq 0.05$) among cashew clones within and across sites (Table 3). At Naliendele, the results indicated the heaviest mean kernel weights of 2.7 g on AC4, while clone AZA2 performed poorly by producing the lightest kernels (1.9 g). At Nanyanga, clones AC10 and AC10/220 out-weighed the rest of the clones by producing kernels weighing 2.6 g. The inferior clone for kernel weight (1.8 g) was AC4/285. Comparisons of mean kernel weights at Nyangao, showed the highest kernel weight (2.7 g) produced by AC10. Clone AZA2 had the least mean kernel weight of 1.9 g.

The highest and lowest mean kernel weights of 2.6 and 1.9 g across locations were obtained on AC10 and AZA2, respectively, with overall mean kernel weight of 2.3 g. Naliendele and Nyangao sites gave equal overall mean kernel weights (2.3 g), which were not significantly different ($P \leq 0.05$) from that recorded at Nanyanga (2.2 g).

4.5.3 Percentage kernel out-turn

The investigation revealed significant variability ($P \leq 0.05$) in mean percentage kernel out-turns among clones (Table 3). Clone AC4/285 exhibited superiority on the mean percentage kernel out-turn (34.5 %), while AC10 gave the lowest mean percentage kernel out-turns (29.0 %) at Naliendele. Significant variations ($P \leq 0.05$) were also observed at Nanyanga, where AZA17 with mean percentage kernel out-turn of 33.3 % performed best, and AC10/220 recorded the least mean percentage kernel out-turn (29.6 %). On ranking the clones at Nyangao according to mean percentage kernel out-turns, the maximum and minimum mean percentage kernel out-turns were found on AC4/285 and AC10/220 with respective values of and 32.1 and 27.7 %.

Across the locations, AC4/285 displayed the highest mean percentage kernel out-turn (33.0 %), while the least mean percentage kernel out-turn (29.2 %) was obtained on AC10/220. The overall mean percentage kernel out-turn across the three sites was 30.9 %. Naliendele was the location that outperformed in the overall average percentage kernel out-turn (31.7 %). The lowest overall mean percentage kernel out-turn was obtained at Nyangao with 29.7 %. According to the investigation, Nanyanga site ranked second after Naliendele site by measuring an overall mean percentage kernel out-turn of 31.4 %.

4.5.4 Nut length

Cashew nut length differed significantly ($P \leq 0.05$) as presented in Table 4. Clone AC10 ranked first at Naliendele by giving nuts with mean length of 3.19 cm. On the other hand, the shortest mean nuts (2.55 cm) were of AZA17. The results of nut length at Nanyanga identified AC10/220 and AZA17 as the longest and shortest nuts, with average lengths of 3.35 and 2.73 cm, respectively. Amongst the seven clones, AC10 gave the superior nuts with mean length of 3.30 cm at Nyangao, while clone AZA17 produced the inferior nuts with a mean length of 2.87 cm.

Table 4. Means for cashew nut length, thickness and boiling time at Naliendele, Nanyanga and Nyangao

Clone	Nut length (cm)				Nut thickness (cm)				Nut boiling time (min)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AC10	3.19^{a}	3.25^{a}	3.30^{a}	3.25^{a}	1.50^{a}	1.54^{a}	1.60^{a}	1.55^{a}	37^{c}	38^{d}	38^{b}	38^{c}
AC4	3.14^{a}	3.14^{b}	3.21^{b}	3.16^{b}	1.33^{b}	1.37^{b}	1.39^{abc}	1.36^{c}	49^{a}	43^{b}	34^{c}	42^{b}
AC14	3.10^{a}	2.97^{c}	3.07^{c}	3.05^{c}	1.33^{b}	1.26^{bc}	1.33^{bc}	1.31^{d}	31^{f}	32^{e}	31^{d}	31^{e}
AC10/220	2.95^{b}	3.35^{a}	3.22^{b}	3.17^{b}	1.38^{b}	1.50^{a}	1.45^{ab}	1.44^{b}	45^{b}	46^{a}	45^{a}	45^{a}
AC4/285	2.87^{b}	2.83^{d}	3.03^{c}	2.91^{d}	1.23^{c}	1.16^{cd}	1.25^{bc}	1.21^{e}	33^{d}	40^{c}	31^{d}	35^{d}
AZA2	2.85^{b}	2.95^{c}	3.06^{c}	2.95^{d}	1.09^{d}	1.14^{cd}	1.34^{bc}	1.19^{e}	26^{g}	28^{f}	29^{e}	28^{f}
AZA17	2.55^{c}	2.73^{d}	2.87^{d}	2.72^{e}	1.02^{e}	1.10^{d}	1.19^{c}	1.10^{f}	32^{e}	39^{c}	31^{d}	34^{d}
Overall mean	2.95	3.03	3.11	3.03	1.27	1.30	1.36	1.31	36	38	34	36
s.e. (±)	0.04	0.04	0.02	0.02	0.02	0.04	0.08	0.03	0.26	0.26	0.31	0.32
c.v. (%)	4.3	3.65	2.2	4.1	5.3	8.77	15.3	10.6	2.3	1.9	2.5	4.6

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

Mean nut lengths across the three locations ranged from 2.72 to 3.25 cm for AZA17 and AC10, respectively, with overall mean of 3.03 cm. Based on locations, Nyangao was the site which produced nuts with overall longest mean (3.11 cm), while Naliendele gave the shortest nuts (2.95 cm). The overall mean nut length obtained at Nanyanga was (3.03 cm).

4.5.5 Nut thickness

The results for cashew nut thickness showed significant variations ($P \leq 0.05$) among clones not only within, but also across the three locations (Table 4). Determination of the cashew nut thickness at Naliendele recorded the least (1.02 cm) and highest (1.50 cm) mean thickness on AZA17 and AC10, respectively. The study also revealed significant variations ($P \leq 0.05$) in nut thickness among the clones at Nanyanga, where AC10 gave the highest mean nut thickness (1.54 cm) while AZA17 recorded the least nut thickness (1.10 cm). Similarly, the clones also exhibited superior and inferior performance at Nyangao with mean thicknesses of 1.60 and 1.19 cm for AC10 and AZA17, respectively.

The mean nut thickness across the sites varied significantly ($P \leq 0.05$) from 1.10 to 1.55 cm, for AZA17 and AC10, respectively. Overall mean of nut thickness across the locations was 1.31 cm. The maximum and minimum overall mean nut thicknesses were observed at Nyangao and Naliendele, with respective values of 1.36 and 1.27 cm, while the overall mean nut thickness at Nanyanga was 1.30 cm.

4.5.6 Nut boiling time

The means for nut boiling time are summarised in Table 4. The nut boiling time at Naliendele showed the shortest mean nut boiling time (26 min) on AZA2, which differed significantly ($P \leq 0.05$) from AC4 that had the longest mean nut boiling time (49 min). The minimum (28 min) and maximum (46 min) mean nut boiling time at Nanyanga were recorded on AZA2 and AC10/220, respectively. Similar variability in nut boiling time was observed at Nyangao; where the least mean nut boiling time (29 min) was obtained on AZA2, while AC10/220 nuts gave the longest mean boiling time (45 min).

Significant variations ($P \leq 0.05$) among clones in mean nut boiling time were also experienced across the locations, with means ranging from 28 to 45 min for AZA2 and AC10/220, respectively and overall mean of 36 min. The shortest (34 min) and longest (38 min) overall mean nut boiling time were observed at Nyangao and Nanyanga, respectively. The overall mean of nut boiling time (36 min) was recorded at Naliendele.

4.6 Nutritional quality of the cashew nut kernels

4.6.1 Fat content

The fat contents observed in cashew kernels are shown in Table 5. The results indicated significant differences ($P \leq 0.05$) in fat contents among the treatments. Clone AC10/220 performed best in mean fat content (48.7 %) at Naliendele, while the clone AC4/285 was found to have the least mean fat content of 45 %. Comparison of fat contents among clones revealed an outstanding performance of clone AC10 at Nanyanga, where it produced mean fat contents of 49.7 %; in contrast AC4 contained the least mean fat content (40.3 %). Analysis of mean fat contents in cashew kernels harvested at Nyangao, indicated that AC10 once again surpassed other clones by containing 49.2 %. At that location, AC14 showed the lowest fat status by composing mean fat content of 44.1 %.

The clone AC10 outperformed across the locations by producing the mean fat content of 48.8 %, while AC4 gave the minimum fat content of 44.5 to %. The overall mean fat content across the three locations was 46.5 %. Cashew kernels from Naliendele and Nyangao sites had equal mean percentages of fat (47.0 %). Cashew kernels from Nanyanga had the overall mean fat content of 45.6 %.

Table 5. Means for fat, protein and phosphorus contents recorded in the cashew kernels at Naliendele, Nanyanga and Nyangao

Clone	Fat content (%)				Protein content (%)				Phosphorus content (%)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AC10/220	48.7^{a}	47.9^{b}	47.6^{c}	48.1^{ab}	17.9^{e}	18.1^{b}	17.0^{d}	17.7^{c}	0.44^{a}	0.47^{d}	0.51^{a}	0.47^{ab}
AC14	47.9^{b}	42.5^{e}	44.1^{f}	44.8^{c}	18.4^{d}	17.4^{d}	18.3^{a}	18.0^{bc}	0.44^{a}	0.49^{c}	0.45^{d}	0.46^{abc}
AZA2	47.6^{c}	46.9^{c}	46.2^{e}	46.9^{b}	19.6^{b}	17.8^{c}	17.9^{b}	18.4^{ab}	0.44^{a}	0.50^{b}	0.47^{c}	0.47^{ab}
AC10	47.5^{c}	49.7^{a}	49.2^{a}	48.8^{a}	20.1^{a}	18.7^{a}	17.4^{c}	18.7^{a}	0.41^{c}	0.51^{a}	0.51^{a}	0.48^{a}
AC4	46.4^{d}	40.3^{f}	46.9^{d}	44.5^{c}	17.3^{f}	17.7^{c}	16.6^{e}	17.2^{d}	0.42^{b}	0.44^{e}	0.51^{a}	0.46^{bc}
AZA17	46.0^{e}	47.7^{b}	48.2^{b}	47.3^{b}	19.1^{c}	18.7^{a}	17.4^{d}	18.4^{ab}	0.42^{b}	0.49^{c}	0.51^{a}	0.47^{ab}
AC4/285	45.0^{f}	44.1^{d}	47.0^{d}	45.4^{c}	17.2^{g}	16.2^{e}	15.2^{f}	16.2^{e}	0.41^{c}	0.44^{e}	0.48^{b}	0.44^{c}
Overall mean	47.0	45.6	47.0	46.5	18.5	17.8	17.1	17.8	0.43	0.48	0.49	0.46
s.e. (±)	0.15	0.151	0.121	0.086	0.84	0.020	0.006	0.168	2.780	0.003	0.002	0.001
c.v. (%)	0.6	0.9	0.7	1.0	0.3	0.3	0.1	4.8	2.2	1.7	1.0	1.5

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

4.6.2 Protein content

Table 5 shows the results of mean protein contents in cashew kernels. Generally, the observations indicated that the mean protein contents varied significantly ($P \leq 0.05$) among clones and locations. At Naliendele site, AC10 was the leading clone in protein content. It contained 20.1 % mean protein, which differed from the least mean protein content (17.2 %) measured on AC4/285. The variations were also found at Nanyanga, where the clone AC10 and AZA17 produced the highest percent of mean protein content (18.7 %), while AC4/285 recorded the lowest mean protein amount (16.2 %). On the other hand, while the highest mean protein content in kernels picked at Nyangao was recorded on AC14, clone AC4/285 gave the lowest mean protein content, with respective values of 18.3 and 15.21 %.

The lowest and highest mean protein contents across the three sites were 16.2 and 18.7 % recorded on AC4/285 and AC10, respectively. The overall mean of protein content across the locations was 17.8 %. Naliendele was the best location for producing cashew nuts with overall mean protein content (18.5 %) as compared with Nanyanga and Nyangao sites where each produced overall mean protein contents of 17.8 and 17.1 %, respectively.

4.6.3 Phosphorus content

Phosphorus content varied significantly ($P \leq 0.05$) among clones as shown in Table 5. Cashew kernels from Naliendele location indicated superiority in mean phosphorus content (0.44 %) on AC10/220. Similar mean phosphorus contents found on AC14 and AZA2. The least amount of mean phosphorus content (0.41 %)

was recorded on AC4/285. The nutritional value evaluation further showed that AC10 was the leading clone in mean phosphorus content at Nanyanga by containing 0.51 %, while AC4/285 and AC4 had the lowest mean contents (0.44 %). The clone AC10 was also superior at Nyangao in mean phosphorus content where it was found to contain 0.51 %. Clones AC10/220, AC4 and AZA17 composed of similar mean phosphorus quantities (0.51 %). At this location the clone AZA2 had the lowest phosphorus content with a mean of 0.47 %.

The maximum (0.48 %) and minimum (0.44 %) mean phosphorus contents across the three locations were recorded on AC10 and AC4/285, respectively with the overall mean of 0.46 %. Nyangao site recorded the highest overall mean phosphorus content (0.49 %). The least overall mean phosphorus content (0.43 %) was found at Naliendele. At Nanyanga, the overall mean of phosphorus content was 0.48 %.

4.6.4 Calcium content

The means for calcium contents in cashew kernels varied significantly at $P \leq 0.05$ (Table 6). The study showed that clone AC10/220 at Naliendele location was the best with the mean calcium content of 489.8 mg/kg, in contrast to clone AC4 which recorded the lowest mean content (367.8 mg/kg). The variations on mean calcium content were also observed among the clones at Nanyanga. The highest mean calcium content (690.4 mg/kg) was revealed on AC14, in contrast to clones AC10/220 and AZA17, which measured the lowest contents with similar means of 347.8 mg/kg. The inconsistency in mean calcium content among clones was also exhibited in cashew nuts harvested at Nyangao. This was evident when comparing the differences between the highest (1367.6 mg/kg) and least (381.2 mg/kg) means of calcium in cashew kernels analysed on AC14 and AC10/220, respectively.

The results of calcium contents across the three locations identified the outstanding mean content (815.9 mg/kg) in AC14, while the lowest mean calcium content (383.9 mg/kg) on AZA17. The overall mean calcium content was 504.0 mg/kg. Determination of calcium based on location revealed that the overall mean of calcium content in cashew nuts picked at Nyangao was superior (602.1 mg/kg) over cashew nuts from Nanyanga (475.6 mg/kg) and Naliendele (434.3 mg/kg).

Table 6. Means for calcium, iron and zinc contents recorded in the cashew kernels at Naliendele, Nanyanga and Nyangao

Clone	Calcium content (mg/kg)				Iron content (mg/kg)				Zinc content (mg/kg)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AC10/220	489.8^{a}	347.8^{f}	381.2^{f}	406.3^{c}	88.1^{c}	106.5^{c}	86.0^{c}	93.5^{ab}	32.5^{b}	28.8^{f}	31.9^{c}	31.1^{bc}
AZA2	489.8^{a}	389.6^{e}	381.2^{f}	420.2^{c}	88.1^{c}	94.2^{d}	65.5^{f}	82.6^{b}	30.5^{d}	30.7^{e}	28.5^{f}	29.9^{c}
AC4/285	473.2^{a}	473.2^{c}	548.4^{c}	498.3^{bc}	91.9^{b}	75.7^{f}	92.1^{b}	86.6^{b}	33.9^{a}	30.8^{d}	34.8^{a}	33.2^{a}
AC10	432.2^{b}	657.1^{b}	740.6^{b}	610.0^{b}	75.7^{e}	131.1^{b}	75.7^{d}	94.2^{ab}	28.1^{g}	33.4^{a}	30.4^{e}	30.6^{c}
AZA17	397.8^{c}	347.8^{f}	406.2^{d}	383.9^{c}	86.0^{d}	86.0^{e}	102.4^{a}	91.5^{ab}	30.2^{e}	31.7^{c}	34.7^{b}	32.2^{ab}
AC14	389.6^{c}	690.4^{a}	1367.6^{a}	815.9^{a}	92.6^{a}	139.3^{a}	71.6^{e}	101.2^{a}	29.5^{f}	33.3^{b}	31.4^{d}	31.4^{bc}
AC4	367.8^{d}	423.1^{d}	389.6^{e}	393.5^{e}	88.0^{c}	94.2^{d}	75.7^{d}	86.0^{b}	32.1^{c}	28.3^{g}	31.4^{d}	30.6^{c}
Overall mean	434.3	475.6	602.1	504.0	87.2	103.9	81.3	90.8	31.0	31.0	31.9	31.3
c.v. (%)	4.60	0.02	0.01	2.30	0.2	0.03	0.1	0.1	0.30	0.03	0.02	0.1
s.e. (±)	3.310	0.032	0.020	2.196	12.65	0.012	0.014	0.021	10.41	0.003	0.002	0.008

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

4.6.5 Iron content

The results from this experiment found that iron contents varied significantly ($P \leq 0.05$) among clones across and within the sites (Table 6). While AC14 ranked first in mean iron content at Naliendele (92.6 mg/kg), the least mean iron content (75.7 mg/kg) was obtained on AC10. The clone AC14 also ranked first in mean iron content at Nanyanga (139.9 mg/kg), while the clone AC4/285 possessed the lowest mean iron content (75.7 mg/kg). The results from this research also indicated significant variability ($P \leq 0.05$) in mean iron contents among the seven clones grown at Nyangao. The clones AZA17 and AZA2 were revealed to contain the highest (102.4 mg/kg) and lowest (65.5 mg/kg) mean iron contents, respectively.

Investigations across the three locations indicated significant variations ($P \leq 0.05$) in mean iron contents ranging from 82.6 to 101.2 mg/kg with an overall mean of 90.8 mg/kg. The lowest iron content was found on AZA2 while highest iron content was recorded on AC14. On overall, Nanyanga site was the best location in producing cashew kernels with highest overall mean of iron (103.9 mg/kg). On the other hand, Nyangao produced cashew nuts with least iron content (81.3 mg/kg). Overall mean iron content in cashew harvested at Naliendele was 87.2 mg/kg.

4.6.6 Zinc content

Significant variability ($P \leq 0.05$) were observed among clones within and across sites in mean zinc contents (Table 6). Clone AC4/285 outperformed the rest of the clones in mean zinc content at Naliendele, where it gave 33.9 mg/kg. Contrary to this, AC10 was the poorest clone and recorded 28.1 mg/kg mean zinc content. On the other hand, at Nanyanga, the clone AC10 produced the highest mean zinc content (33.4 mg/kg), while the lowest mean zinc content (28.3 mg/kg) was found on AC4. The clone AC4/285 also showed the superiority over others at Nyangao by containing 34.8 mg/kg mean zinc. Clone AZA2 was regarded as inferior in zinc content with mean of 28.5 mg/kg.

The mean zinc contents across the three locations were lowest (29.9 mg/kg) in AZA2 and highest (33.2 mg/kg) in AC4/285, while overall mean was 31.3 mg/kg. The overall mean of zinc content was higher at Nyangao (31.9 mg/kg) than at Naliendele and Nanyanga sites, which measured an equal quantity of 31.0 mg/kg.

4.6.7 Copper content

The results indicated the best performance of AZA17 in copper content at Naliendele, where the mean quantity of copper in cashew kernels was 19.7 mg/kg, which differed significantly ($P \leq 0.05$) from AC10 that showed the poorest performance by containing 13.7 mg/kg (Table 7). The superior characteristics of AZA17 in mean copper content were also expressed at Nanyanga by measuring 17.7 mg/kg, while AC4 recorded the least mean copper content (13.7 mg/kg). Copper determination in cashew kernels from Nyangao again identified AZA17 as an out-performing clone, which gave 18.5 mg/kg; at the same time AC10 was found to have the lowest mean copper content of 14.1 mg/kg.

Table 7. Means for copper, magnesium and potassium contents recorded in the cashew kernels at Naliendele, Nanyanga and Nyangao

Clone	Copper (mg/kg)				Magnesium (%)				Potassium content (%)			
	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean	Naliendele	Nanyanga	Nyangao	Mean
AZA17	19.7^{a}	17.7^{a}	18.5^{a}	18.6^{a}	0.23^{b}	0.27^{a}	0.28^{a}	0.26^{a}	0.54^{c}	0.54^{c}	0.57^{d}	0.55^{c}
AC4/285	18.9^{b}	16.5^{c}	17.7^{b}	17.7^{b}	0.23^{b}	0.23^{c}	0.24^{c}	0.23^{c}	0.44^{e}	0.44^{e}	0.50^{g}	0.46^{e}
AC10/220	18.5^{c}	16.1^{d}	16.1^{c}	16.9^{c}	0.25^{a}	0.21^{d}	0.25^{b}	0.24^{c}	0.62^{a}	0.62^{a}	0.54^{e}	0.59^{b}
AC14	18.5^{c}	15.3^{e}	14.1^{e}	16.0^{de}	0.21^{d}	0.26^{b}	0.28^{a}	0.25^{ab}	0.58^{a}	0.58^{b}	0.77^{a}	0.64^{a}
AZA2	17.3^{d}	16.9^{b}	14.9^{d}	16.4^{cd}	0.25^{a}	0.26^{b}	0.25^{b}	0.25^{a}	0.51^{d}	0.51^{d}	0.62^{b}	0.55^{c}
AC4	16.1^{e}	13.7^{g}	16.1^{c}	15.3^{e}	0.22^{c}	0.23^{c}	0.24^{c}	0.23^{c}	0.62^{a}	0.62^{a}	0.61^{c}	0.62^{ab}
AC10	13.7^{f}	14.9^{f}	14.1^{e}	14.2^{f}	0.22^{bc}	0.26^{b}	0.24^{c}	0.24^{bc}	0.50^{d}	0.50^{d}	0.52^{f}	0.51^{d}
Overall mean	17.5	15.9	15.9	16.4	0.23	0.25	0.25	0.24	0.54	0.54	0.59	0.56
s.e. (±)	2.090	0.003	0.002	0.001	0.39	0.003	0.002	0.001	0.61	0.003	0.002	0.001
c.v. (%)	0.1	0.05	0.04	0.04	4	3.2	2.3	2.9	1.6	1.6	1.0	1.3

Means with the same superscript letter(s) in the same column are not significantly different following Duncan's Multiple Range Test ($P \leq 0.05$).

Generally, mean copper contents varied significantly ($P \leq 0.05$) across the sites. The contents ranged from 14.2 to 18.6 mg/kg, with overall mean of 16.4 mg/kg. The lowest and highest range values were found on AC10 and AZA17, respectively. Naliendele site recorded higher overall mean of copper (17.5 mg/kg) than Nanyanga and Nyangao, where both sites had cashew kernels with the copper contents of 15.9 mg/kg.

4.6.8 Magnesium content

Variability in mean magnesium contents found among clones was significant ($P \leq 0.05$) as shown in Table 7. While the clones AC10/220 and AZA2 gave the highest mean magnesium contents of 0.25 % at Naliendele, the clone AC14 contained the least mean magnesium quantity (0.21 %). The chemical analysis further identified that while the magnesium content at Nanyanga was highest (0.27 %) on AZA17, cashew kernels of AC10/220 showed the minimum average magnesium content of 0.21 %. Significant variations ($P \leq 0.05$) among clones in mean magnesium contents were also noticed at Nyangao, where the topmost clones in magnesium content were AZA17 and AC14. Their kernel compositions showed 0.28 % mean magnesium, while AC10, AC4 and AC4/285 were revealed as inferior clones by recording the lowest mean magnesium contents of 0.24 %.

The overall magnesium mean content across the three locations was 0.24 %. The maximum mean magnesium content (0.26 %) was recorded on clone AZA17. Clones AC4 and AC4/285 displayed the lowest mean magnesium content each with 0.23 %. Nanyanga and Nyangao locations gave similar overall means of magnesium contents (0.25 %), while the cashew nuts picked at Naliendele had kernels which contained 0.23 % mean magnesium content.

4.6.9 Potassium content

The investigation on the cashew kernels nutritional values revealed significant variations ($P \leq 0.05$) in potassium contents among the seven clones within and across locations (Table 7). Evaluations of cashew kernels from Naliendele indicated that clones AC10/220 and AC4 performed best for this parameter with the means of 0.62 % potassium content. On contrary, the clone AC4/285 showed poor performance with the least mean potassium content of 0.44 %. Similar results were observed at Nanyanga location. At Nyangao, clone AC14 was leading by recording mean potassium content of 0.77 %, while the clone AC4/285 had the lowest mean potassium content (0.50 %).

Moreover, the results showed that mean potassium contents among the clones were also observed across locations. The contents ranged from 0.46 to 0.64 % for AC4/285 and AC14, respectively with overall mean of 0.56 %. The highest overall mean of potassium content (0.59 %), was observed at Nyangao. Naliendele and Nanyanga gave the lowest potassium contents; each location with a mean of 0.54 %.

4.6.10 Sodium content

The results for means of sodium contents in cashew kernels are summarized in Table 8. This investigation showed that clone AC10/220 outperformed at Naliendele with the mean sodium content of 145.5 mg/kg, which differed significantly ($P \leq$

0.05) from the clones AZA17 and AC4 that had the minimum mean sodium contents of 105.6 mg/kg.

Table 8. Means for sodium content recorded in the cashew kernels at Naliendele, Nanyanga and Nyangao

Clone	Naliendele (mg/kg)	Nanyanga (mg/kg)	Nyangao (mg/kg)	Mean (mg/kg)
AC10/220	145.5^{a}	95.6^{g}	159.5^{a}	133.5^{a}
AC14	127.5^{b}	145.5^{b}	113.6^{e}	128.9^{ab}
AC10	119.6^{c}	147.5^{a}	133.5^{d}	133.5^{a}
AZA2	115.6^{d}	127.5^{c}	101.6^{g}	114.9^{bc}
AC4/285	107.6^{e}	107.6^{e}	109.6^{f}	108.3^{c}
AC4	105.6^{f}	117.6^{d}	153.5^{b}	125.6^{ab}
AZA17	105.6^{f}	97.6^{f}	141.5^{c}	114.9^{bc}
Overall mean	118.1	119.8	130.4	122.8
s.e. (±)	0.01	0.015	0.016	0.006
c.v. (%)	0.02	0.03	0.03	0.03

Means with the same superscript letter(s) in the same column are not significantly different as per Duncan's Multiple Range Test ($P \leq 0.05$).

At Nanyanga, superiority in mean sodium content (147.5 mg/kg) was found on AC10. Conversely, AC10/220 measured the lowest mean sodium content (95.6 mg/kg). Mineral analysis of cashew kernels from Nyangao revealed the highest mean sodium content (159.5 mg/kg) on AC10/220, and the lowest mean content (101.6 mg/kg) on AZA2.

Means of sodium contents across the three locations differed significantly ($P \leq 0.05$), with an overall mean of 122.8 mg/kg. The least mean sodium content (108.3 mg/kg) was measured on AC4/285, while the maximum value (133.5 mg/kg) was recorded on clones AC10 and AC10/220. With respect to the overall mean sodium content per location, Nyangao was the best site which gave significantly ($P \leq 0.05$) the highest overall mean (130.4 mg/kg) as compared to other locations. The least overall mean sodium content (118.1 %) was recorded at Naliendele. On the other hand, Nanyanga site recorded the overall mean sodium content of 119.8 mg/kg.

4.7 Genetic correlations between some cashew traits at Naliendele, Nanyanga and Nyangao.

The correlation coefficients of cashew nut yield and yield components are shown in Table 9. At Naliendele, very highly significant positive correlations were observed between yield per season and yield per day (r = 0.678***); nut weight and kernel weight (r = 0.622***); nut weight and nut length (r = 0.503***). This study also revealed very highly significant positive correlation between kernel weight and nut length (r = 0.690***). Nut picking duration was very highly significant and negatively correlated with yield per day (r = -0.679***). Yield per season showed significant and negative correlation with nut weight (r = -0.281*).

Table 9. Genotypic correlations between some cashew traits at three locations

Location		YPS	NPD	YPD	NWT	KWT	NL
Naliendele	YPS	1	-0.028	0.678***	-0.281*	-0.140	-0.136
	NPD		1	-0.679***	0.084	0.176	0.330*
	YPD			1	-0.241	-0.157	-0.309**
	NWT				1	0.622***	0.503***
	KWT					1	0.690***
	NL						1
Nanyanga	YPS	1	0.396**	0.787***	-0.377**	-0.434***	-0.485***
	NPD		1	-0.229	0.106	-0.041	-0.060
	YPD			1	-0.497	-0.434***	-0.530***
	NWT				1	0.711***	0.784**
	KWT					1	0.790***
	NL						1
Nyangao	YPS	1	0.053	0.868***	-0.242	-0.158	-0.310*
	NPD		1	-0.412***	0.536***	0.343**	0.257*
	YPD			1	-0.422***	-0.280*	-0.378*
	NWT				1	0.702***	0.679***
	KWT					1	0.632***
	NL						1

YPS = Yield/season; NPD = Nut picking duration; YPD = Yield/day; NWT = Nut weight; KWT = Kernel weight; NL = Nut length

Comparisons of the cashew nut yield components from Nanyanga showed very highly significant and positive correlations between yield per season and yield per day (r = 0.787***); nut weight and kernel weight (r = 0.711***); nut weight and nut length (r = 0.784***); also between kernel weight and nut length (r = 0.790***). Yield per day and nut length were very highly significant and negatively correlated (r = -0.530***). The correlations between yield per day and nut weight was negative but very highly significant (r = -0.497***).

Yield per season was very highly significant and positively correlated with yield per day at Nyangao (r = 0.868***). The other positive and very highly significant correlations were observed between nut picking duration and nut weight (r = 0.536***); nut weight and kernel weight (r = 0.702***); nut weight and nut length (r = 0.679***); and between kernel weight and nut length (r = 0.632***). Yield per day was negatively correlated with nut weight (r = -0.422***) and also very highly significant.

In addition to the correlations observed at different locations, in a combined analysis altitude was found to be highly significant and negatively correlated with cashew nut yield per season (r = -0.495**) and nut yield per day (r = -0.517**) as shown in Table 10. Other relationships under the combined analysis were between cashew nut yield per day and nut picking duration which was highly significant and negative correlated (r = -0.659**). Highly significant positive correlations were observed between nut yield per season and nut yield per day (r = 0.799**); nut weight and kernel weight (r = 0.638**). Moreover, nut weight and nut length (r = 0.622**);

kernel weight and nut length (r = 0.676**); kernel weight and nut thickness (r = 0.554**); nut length and nut thickness (r = 0.719**); also nut weight and nut thickness (r = 0.603**) were positively correlated and highly significant. Furthermore, highly significant but positive correlation (r = 0.179**) was observed between protein and fat content in the cashew kernels.

Table 10. Genetic correlations between variables influencing cashew performance as observed in a combined analysis

	YPS	NPD	YPD	NWT	KWT	PKOT	NL	NT	NBT	FC	PC	ALT
YPS	1	-0.170**	0.799**	-0.286**	-0.158*	0.360**	-0.325**	-0.279**	-0.066	-0.053	0.003	-0.495**
NPD		1	-0.659**	0.309**	0.143*	-0.158*	0.316**	0.302**	-0.075	0.011	-0.111	0.247**
YPD			1	-0.317**	-0.145*	0.401**	-0.407**	-0.333**	0.030	-0.053	0.054	-0.517**
NWT				1	0.638**	-0.345**	0.622**	0.603**	0.403**	0.169**	-0.078	-0.041
KWT					1	0.054	0.676**	0.554**	0.405**	0.191**	0.002	-0.066
PKOT						1	-0.413**	-0.381**	-0.023	-0.258**	-0.092	0.019
NL							1	0.719**	0.344**	0.162	-0.067	0.109
NT								1	0.371**	0.191**	-0.008	0.024
NBT									1	0.033	-0.125	0.121
FC										1	0.179**	-0.330**
PC											1	-0.189**
ALT												1

* $P \leq 0.05$; ** $P \leq 0.01$; YPS = Yield/season; NPD = Nut picking duration; YPD = Yield/day; NWT = Nut weight; KWT = Kernel weight; PKOT = Percentage kernel out-turn; NL = Nut length; NT = Nut thickness; NBT = Nut boiling time; FC = Fat content; PC = Protein content; ALT = Altitude

On overall, cashew nut yield was revealed to be negatively correlated with altitude (Fig.5). At Naliendele location where the altitude is 102 m above sea level, the highest mean yield (4604.9 kg/ha) was recorded on AC4/285, while AC10 produced the least mean yield of 2691.2 kg/ha. The mean yield of AC4/285 was also superior at Nyangao (174 m above sea level), where it produced 3278.2 kg/ha. The least mean yield at Nyangao (1841.5 kg/ha) was obtained on clone AC10/220. At the altitude of 334 m above sea level, the leading clone (AC4) produced 2762.0 kg/ha, on contrast, clone AC10/220 gave lowest mean yield of 1289.8 kg/ha.

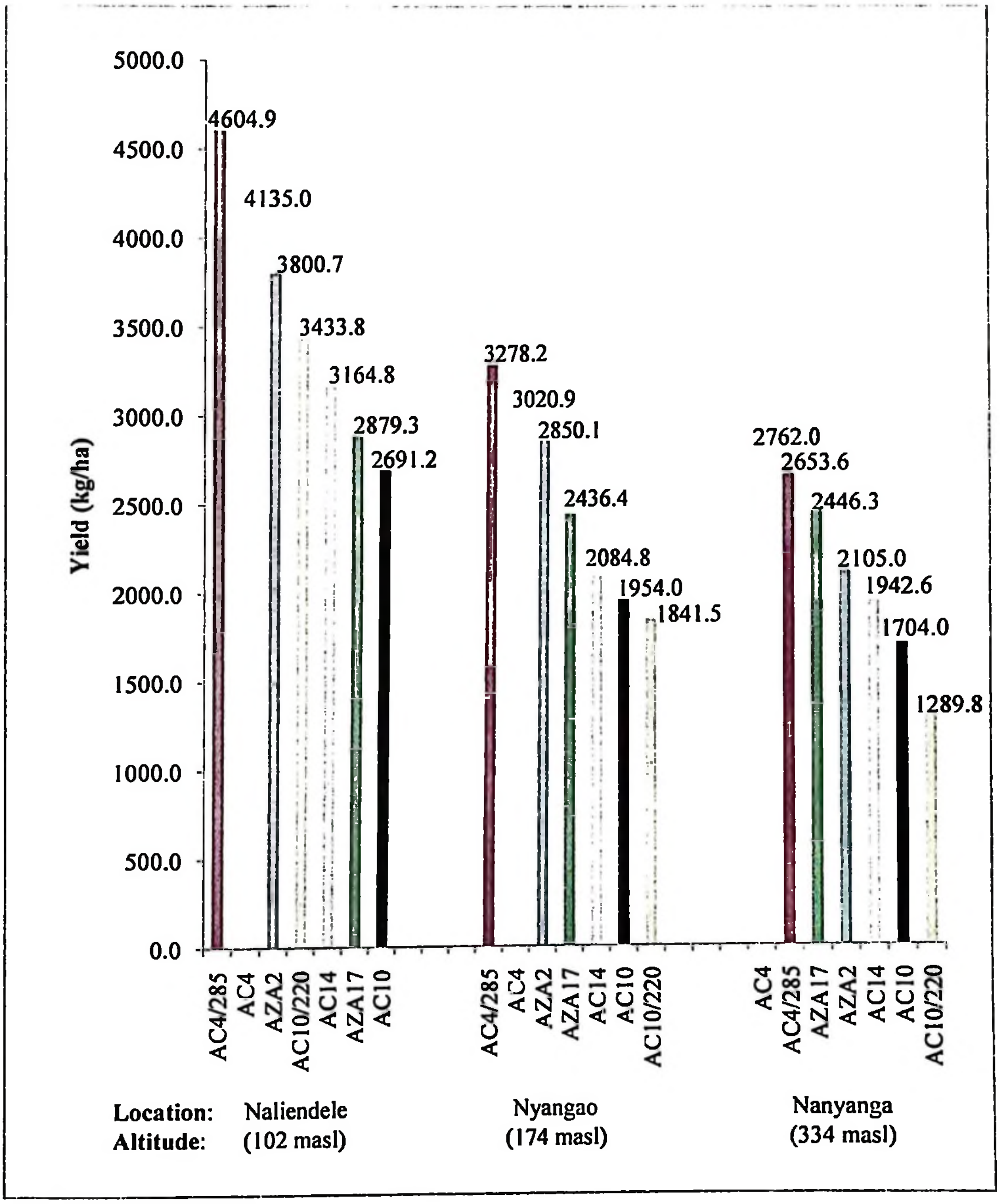
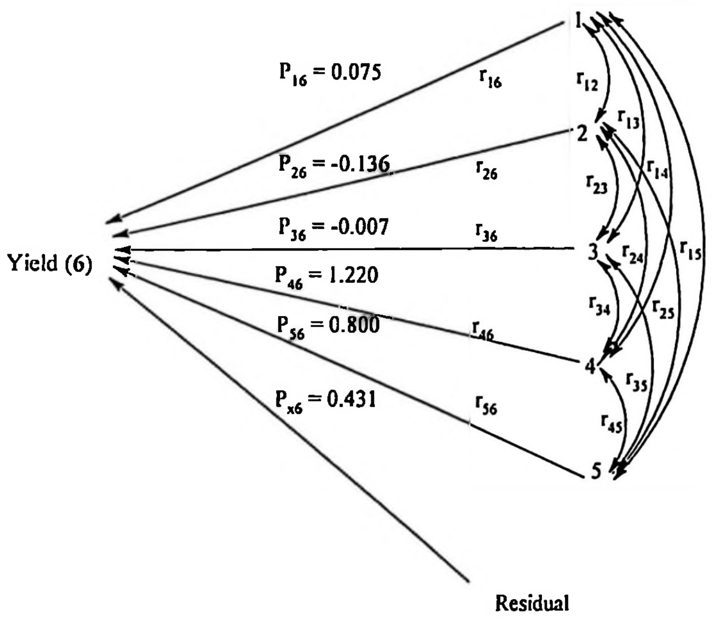


Figure 5. Cashew nut yield variation of seven clones in three sites located at different altitudes

4.8 Associations among cashew nut yield influencing factors at Naliendele, Nanyanga and Nyangao

Results of associations among factors that influenced cashew nut yield at Naliendele as described using path coefficient analyses are shown in Fig. 6 and Table 11. The results indicated significant variability in causal relationships among cashew nut yield influencing factors. The highest genetic correlation on cashew nut yield influencing factors was found on the effect of nut yield per day (r = 0.677). Similarly, the direct effect of yield per day (1.220) showed the greatest effect on cashew nut yield per season. Indirect effect of yield per day via nut picking duration had a negative effect on cashew nut yield per season (-0.543). Direct effect of nut picking duration on cashew nut yield per season was positive (0.800), while its indirect effect via nut yield per day was negative (-0.828). Effects of nut length, kernel weight and nut weight on cashew nut yield per season were negative and highest when observed indirectly via nut yield per day. However, the effects were relatively low (-0.377, -0.192 and -0.294, respectively). Generally, every indirect effects of the variable studied via yield per day was revealed to have the highest influence on cashew nut yield per season.



Where,

1 = nut length	P_{46} = effect of yield/day	r_{13} = 0.503
2 = kernel weight	P_{56} = effect of nut picking duration	r_{14} = -0.309
3 = nut weight	P_{X6} = residual effects	r_{15} = 0.330
4 = yield/day	r_{16} = -0.135	r_{23} = 0.622
5 = nut picking duration	r_{26} = -0.140	r_{24} = -0.157
6 = yield	r_{36} = -0.281	r_{25} = 0.176
P_{16}= effect of nut length	r_{46} = 0.677	r_{34} = -0.241
P_{26} = effect of kernel weight	r_{56} = -0.028	r_{35} = 0.084
P_{36} = effect of nut weight	r_{12} = 0.690	r_{45} = -0.679

P = Direct effect
r = Correlation coefficient

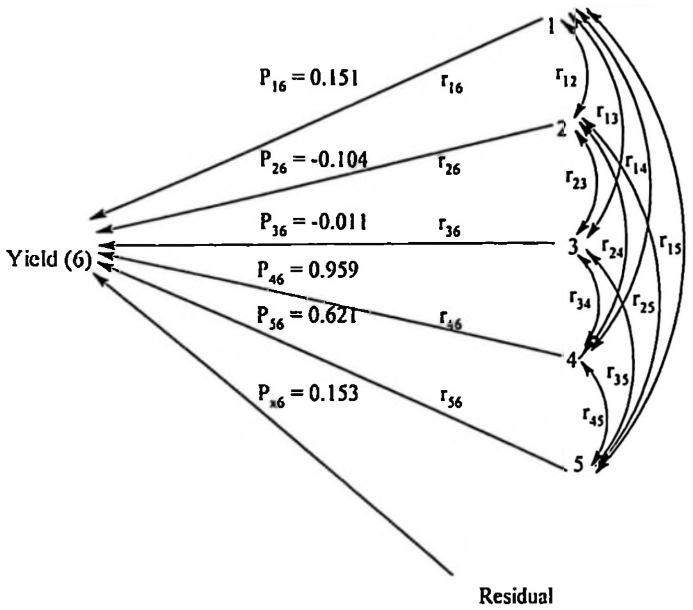
Figure 6. Path diagram showing relationships between yield and yield influencing factors at Naliendele

Table 11. Path coefficients for cashew nut yield influencing factors at Naliendele, Nanyanga and Nyangao

	Effect	Nal	Nan	Nya
1	**Effect of nut length on cashew nut yield, r_{16}**	**-0.135**	**-0.486**	**0.486**
	Direct effect of nut length, P_{16}	0.075	0.151	0.008
	Indirect effect of nut length via kernel weight, $r_{12}P_{26}$	-0.093	-0.083	0.013
	Indirect effect of nut length via nut weight, $r_{13}P_{36}$	-0.004	-0.009	-0.071
	Indirect effect of nut length via nut yield/day, $r_{14}P_{46}$	-0.377	-0.508	-0.398
	Indirect effect of nut length via nut picking duration, $r_{15}P_{56}$	0.264	-0.037	0.137
	Total	**-0.135**	**-0.486**	**0.486**
2	**Effect of kernel weight on cashew nut yield, r_{26}**	**-0.140**	**-0.435**	**-0.159**
	Direct effect of kernel weight, P_{26}	-0.136	-0.104	0.021
	Indirect effect of kernel weight via nut length, $r_{21}P_{16}$	0.052	0.119	0.005
	Indirect effect of kernel weight via nut weight, $r_{23}P_{36}$	-0.004	-0.008	-0.074
	Indirect effect of kernel weight via nut yield/day, $r_{24}P_{46}$	-0.192	-0.416	-0.294
	Indirect effect of kernel weight via nut picking duration, $r_{25}P_{56}$	0.141	-0.026	0.183
	Total	**-0.140**	**-0.435**	**-0.159**
3	**Effect of nut weight on cashew nut yield, r_{36}**	**-0.281**	**-0.377**	**-0.242**
	Direct effect of nut weight, P_{36}	-0.007	-0.011	-0.104
	Indirect effect of nut weight via nut length, $r_{31}P_{16}$	0.038	0.118	0.005
	Indirect effect of nut weight via kernel weight, $r_{32}P_{26}$	-0.085	-0.074	0.015
	Indirect effect of nut weight via nut yield/day, $r_{34}P_{46}$	-0.294	-0.477	-0.444
	Indirect effect of nut weight via nut picking duration, $r_{35}P_{56}$	0.067	0.066	0.286
	Total	**-0.281**	**-0.377**	**-0.242**
4	**Effect of nut yield/day on cashew nut yield, r_{46}**	**0.677**	**0.779**	**0.866**
	Direct effect of nut yield/day, P_{46}	1.220	0.959	1.051
	Indirect effect of nut yield/day via nut length, $r_{41}P_{16}$	-0.023	-0.080	-0.003
	Indirect effect of nut yield/day via kernel weight, $r_{42}P_{26}$	0.021	0.045	-0.006
	Indirect effect of nut yield/day via nut weight, $r_{43}P_{36}$	0.002	0.013	0.044
	Indirect effect of nut yield/day via nut picking duration, $r_{45}P_{56}$	-0.543	-0.142	-0.220
	Total	**0.677**	**0.779**	**0.866**
5	**Effect of nut picking duration on cashew nut yield, r_{56}**	**-0.028**	**0.395**	**0.053**
	Direct effect of nut picking duration, P_{56}	0.800	0.621	0.533
	Indirect effect of nut picking duration via nut length, $r_{51}P_{16}$	0.025	-0.009	0.002
	Indirect effect of nut picking duration via kernel weight, $r_{52}P_{26}$	-0.024	0.004	0.007
	Indirect effect of nut picking duration via nut weight, $r_{53}P_{36}$	-0.001	-0.001	-0.056
	Indirect effect of nut picking duration via nut yield/day, $r_{54}P_{46}$	-0.828	-0.220	-0.433
	Total	**-0.028**	**0.395**	**0.053**

Note: Nal = Naliendele; Nan = Nanyanga; Nya = Nyangao

At Nanyanga, the leading genetic correlation of cashew nut yield influencing factors was positive and found on nut yield per day where r = 0.779 (Table 11 and Figure 7). The direct effect of nut yield per day on cashew nut yield per season also gave the greatest magnitude (0.959). The other positive effect was observed on direct effect of nut picking duration via yield per day (0.621). Indirect effects of nut length (-0.508), kernel weight (-0.416), nut weight (-0.477), and nut picking duration (-0.220) via yield per day were negative. Nevertheless, the indirect effects were weak, except the indirect effect of nut length via yield per day (-0.508).



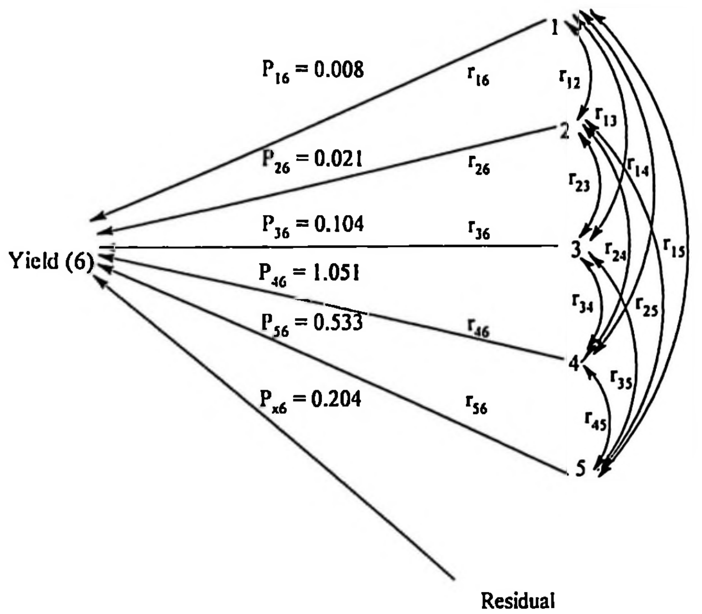
Where,

1 = nut length	P_{46} = effect of yield/day	$r_{13} =$ 0.784
2 = kernel weight	P_{56} = effect of nut picking duration	$r_{14} =$ -0.530
3 = nut weight	P_{X6} = residual effects	$r_{15} =$ -0.060
4 = yield/day	$r_{16} =$ -0.486	$r_{23} =$ 0.711
5 = nut picking duration	$r_{26} =$ -0.435	$r_{24} =$ -0.434
6 = yield	$r_{36} =$ -0.377	$r_{25} =$ -0.041
P_{16}= effect of nut length	$r_{46} =$ 0.779	$r_{34} =$ -0.497
P_{26} = effect of kernel weight	$r_{56} =$ 0.395	$r_{35} =$ 0.106
P_{36} = effect of nut weight	$r_{12} =$ 0.790	$r_{45} =$ -0.229

P = Direct effect
r = Correlation coefficient

Figure 7. Path diagram showing relationships between yield and yield influencing factors at Nanyanga

Table 11 and Fig. 8 present the path analysis coefficients for Nyangao location. Significant influence of direct effects of cashew nut yield per day and nut picking duration on cashew nut yield per season, were revealed at the magnitudes of 1.051 and 0.533, respectively. The highest indirect effects on cashew nut yield per season were found on variables which their effects were determined through nut yield per day; and their effects were consistently negative. The highest genetic correlation (r = 0.866) of the cashew nut yield influencing factors was observed on nut yield per day.



Where,

1 = nut length	P_{46} = effect of yield/day	r_{13} = 0.679
2 = kernel weight	P_{56} = effect of nut picking duration	r_{14} = -0.378
3 = nut weight	P_{X6} = residual effects	r_{15} = 0.257
4 = yield/day	r_{16} = 0.486	r_{23} = 0.702
5 = nut picking duration	r_{26} = -0.159	r_{24} = -0.280
6 = yield	r_{36} = -0.242	r_{25} = 0.343
P_{16}= effect of nut length	r_{46} = 0.866	r_{34} = -0.422
P_{26} = effect of kernel weight	r_{56} = 0.053	r_{35} = 0.536
P_{36} = effect of nut weight	r_{12} = 0.632	r_{45} = -0.412

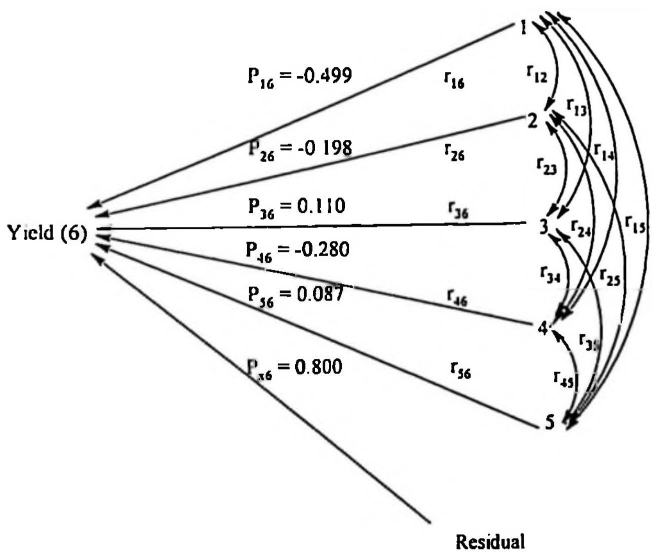
P = Direct effect;

r = Correlation coefficient

Figure 8. Path diagram showing relationships between yield and yield influencing factors at Nyangao

4.9 Associations among cashew nut yield influencing factors in combined analysis

Altitude was revealed to have the highest influence on cashew nut yield (Fig. 9 and Table 12). The altitude had negative correlation coefficient ($r = -0.495$) with cashew yield. In the combined analysis, the direct effect of altitude (-0.499) was realized to be the most important parameter that influenced cashew nut yield.



Where,

1 = altitude	P_{46} = effect of nut weight	r_{13} = -0.065
2 = nut length	P_{56} = effect of nut picking duration	r_{14} = -0.041
3 = kernel weight	P_{X6} = residual effect	r_{15} = 0.247
4 = nut weight	r_{16} = -0.495	r_{23} = 0.676
5 = nut picking duration	r_{26} = -0.325	r_{24} = 0.622
6 = yield	r_{36} = -0.158	r_{25} = 0.316
P_{16}= effect of altitude	r_{46} = -0.286	r_{34} = 0.638
P_{26} = effect of nut length	r_{56} = -0.170	r_{35} = 0.143
P_{36} = effect of kernel weight	r_{12} = 0.109	r_{45} = 0.309

P = Direct effect

r = Correlation coefficient

Figure 9. Path diagram showing relationships between yield and yield influencing factors under combined analysis

Table 12. Path coefficients for combined analysis of cashew nut yield influencing factors

1	**Effect of altitude on cashew nut yield, r_{16}**	**-0.495**
	Direct effect of altitude, P_{16}	-0.499
	Indirect of altitude via nut length, $r_{12}P_{26}$	-0.022
	Indirect of altitude via kernel weight, $r_{13}P_{36}$	-0.007
	Indirect effect of altitude via nut weight, $r_{14}P_{46}$	0.011
	Indirect effect of altitude via nut picking duration, $r_{15}P_{56}$	0.022
	Total	**-0.495**
2	**Effect of nut length on cashew nut yield, r_{26}**	**-0.325**
	Direct effect of nut length, P_{26}	-0.198
	Indirect effect of nut length via altitude, $r_{21}P_{16}$	-0.054
	Indirect effect of nut length via kernel weight, $r_{23}P_{36}$	0.074
	Indirect effect of nut length via nut weight, $r_{24}P_{46}$	-0.174
	Indirect effect of nut length via nut picking duration, $r_{25}P_{56}$	0.028
	Total	**-0.325**
3	**Effect of kernel weight on cashew nut yield, r_{36}**	**-0.158**
	Direct effect of kernel weight, P_{36}	0.110
	Indirect effect of kernel weight via altitude, $r_{31}P_{16}$	0.033
	Indirect effect of kernel weight via nut length, $r_{32}P_{26}$	-0.135
	Indirect effect of kernel weight via nut weight, $r_{34}P_{46}$	-0.179
	Indirect effect of kernel weight via nut picking duration, $r_{35}P_{56}$	0.012
	Total	**-0.158**
4	**Effect of nut weight on cashew nut yield, r_{46}**	**-0.286**
	Direct effect of nut weight, P_{46}	-0.280
	Indirect effect of nut weight via altitude, $r_{41}P_{16}$	0.020
	Indirect effect of nut weight via nut length, $r_{42}P_{26}$	-0.123
	Indirect effect of nut weight via kernel weight, $r_{43}P_{36}$	0.070
	Indirect effect of nut weight via nut picking duration, $r_{45}P_{56}$	0.027
	Total	**-0.286**
5	**Effect of nut picking duration on cashew nut yield, r_{56}**	**-0.170**
	Direct effect of nut picking duration, P_{56}	0.087
	Indirect effect of nut picking duration via altitude, $r_{51}P_{16}$	-0.123
	Indirect effect of nut picking duration via nut length, $r_{52}P_{26}$	-0.063
	Indirect effect of nut picking duration via kernel weight, $r_{53}P_{36}$	0.016
	Indirect effect of nut picking duration via nut weight, $r_{54}P_{46}$	-0.086
	Total	**-0.170**

4.10 Regression analysis

4.10.1 Simple regression analysis

Regression line for cashew nut yield across different altitudes is presented in Fig 10. The regression line indicates that there is a negative correlation between altitude and cashew nut yield suggesting a nut yield decrease with increasing altitude. For example, the yield is highest (3530.0 kg/ha) at the altitude of 102 m above sea level, and is progressively decreasing to the magnitude of 2129.0 kg/ha (at 334 m above sea level).

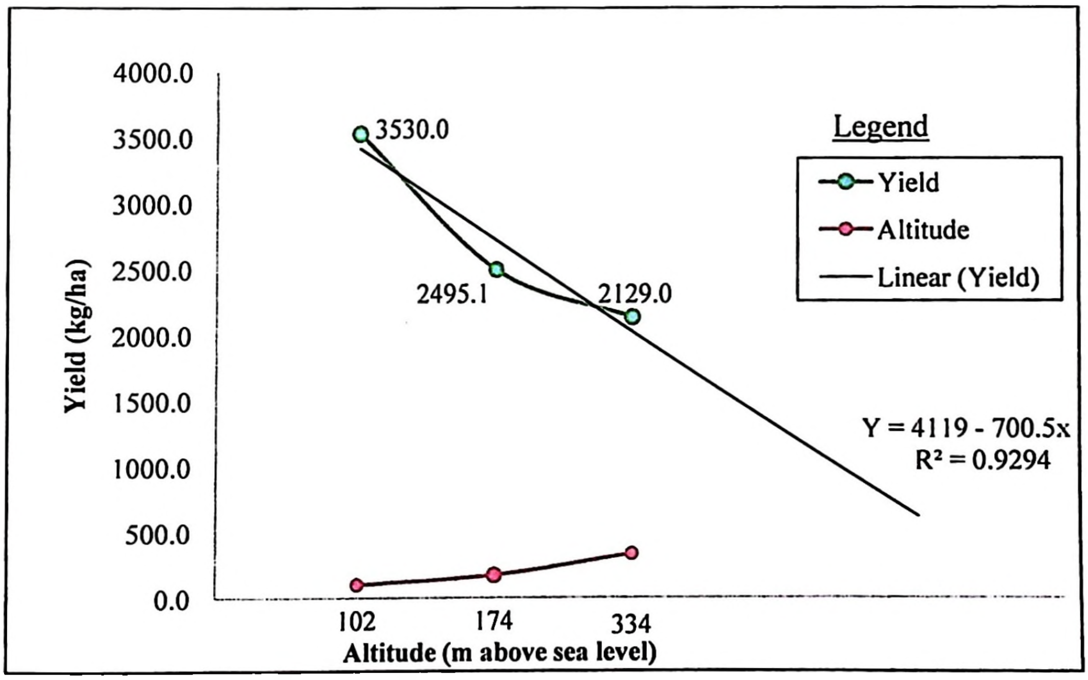


Figure 10. Simple regression forecasting cashew nut yield in different altitudes

This study has revealed that 92.9 % of the total variation in cashew nut yield per season could be explained by variation in the altitude. According to the regression line, the cashew yield could fall with the increasing altitude to the extent that in extremely high altitudes no more yields could be obtained. The cashew nut yield across different altitudes could be estimated using the regression question (model):

$Y = 4119 - 700.5x$.

Where, Y = cashew nut yield/season

x = altitude

R^2 = coefficient of determination

4.10.2 Multiple regression analysis

The results showed that cashew nut yield can be estimated using the models shown in Table 17. According to the model, cashew nut yield per season was significantly correlated with yield per day, nut picking duration, nut weight and altitude. Stepwise multiple regression analysis revealed that 87.59 % of the total variation in cashew nut yield per season could be explained by variation in altitude, while 63.81 % of the variation could be explained by yield per day. In addition, 86.28 and 87.32 % of the cashew nut yield variations could be explained by variability in nut picking duration and nut weight, respectively.

Table 13. Stepwise multiple regressions analysis of cashew nut yield per season and yield influencing factors

Step	Entered variable	Regression equations (models)	Model R-Square	Pr > F
1	Yield/day	$Y = 1263 + 27x_1$	0.6381	<.0001
2	Nut picking duration	$Y = -2299 + 41x_1 + 51x_2$	0.8628	<.0001
3	Nut weight	$Y = -1727 + 41x_1 + 52x_2 - 79x_3$	0.8732	0.0001
4	Altitude	$Y = -1395 + 39x_1 + 51x_2 - 89x_3 - 1x_4$	0.8759	0.0440

Where Y = cashew nut yield/season

x_1 = yield/day

x_2 = Nut picking duration

x_3 = Nut weight

x_4 = Altitude

Model R-Square = Coefficient of determination (R^2)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Cashew nut picking duration

5.1.1 Cashew nut picking duration based on time length

The results from this study showed variations in cashew nut picking duration among clones within and across the three locations. Based on specific clones, AZA17 consistently showed the least mean nut picking duration in all locations. The shortest mean time length taken to complete the cashew nut picking was probably contributed by the shortest mean nut length and thickness. The mean cashew nut picking duration were positively correlated with nut length and thickness. For example, while the mean nut lengths of AZA17 at Naliendele, Nanyanga and Nyangao were 2.55, 2.73 and 2.87 cm, their mean nut picking durations were 34, 51 and 55 days, respectively. Furthermore, the results showed that the overall mean cashew nut picking durations were increasing with increasing overall mean nut length and thickness, suggesting that small nuts exhibit shorter nut picking duration than large ones. The influence of nut length and thickness was observed among and within clones. These imply that the cashew nut picking duration not only varies among clones, but also on a particular clone so long as the mean nut length and thickness are varied. The clone AZA17 was regarded as stable in short nut picking duration; suggesting that it could be grown in a wide range of altitudes without affecting the cashew nut picking duration.

With respect to the environmental factors, Naliendele which had the highest amounts of temperature and rainfall as compared to Nyangao and Nanyanga (Appendix 3), showed the smallest overall mean nut length and thickness and the shortest nut picking duration. The variations observed in the findings suggest that apart from the genotypic performance, probably there are other factors such as rainfall and temperature, which influenced the cashew nut picking duration.

Observations from this study have shown that every cashew genotype has its optimum ability of producing cashew nuts per season at a particular environment. Whether harvesting maturity and consequently nut picking takes short or long time, the optimum yield per season remains the same. Thus, high yielding cashew genotypes that on which few days are taken to complete nut harvesting are considered as suitable genotypes for economical production.

5.1.2 Cashew nut picking duration based on the time of attaining the highest yield proportion

It was realized from this investigation that despite the variations in number of days spent to harvest each individual clone there was also significant variability ($P \leq 0.05$) in the time of starting cashew nut picking, attaining peak harvesting and ending the operation of nut picking. For example, while before middle of the season clone AC4 was ahead of others by producing 97 and 67 % of the total yield at Naliendele and Nanyanga locations, respectively; clone AC4/285 produced 89 % of its total yield at Nyangao. Poor fat and protein compositions in the cashew kernels were the important characteristics exhibited by these clones. The low fat and protein contents in the cashew kernels were probably among other genetic factors influenced the earliness of cashew nut harvesting on these clones. For this matter, the clone AC4 was categorized as the earliest nut maturing at Naliendele and Nanyanga, while AC4/285 was superior at Nyangao.

Identifying and categorising cashew genotype according to this characteristic was found as an essential aspect to consider in cashew improvement programmes. Based on the time of starting nut picking of each clone, it was evident that while some clones had no crop at all at the onset of the season, others had appreciable amounts of the crop to collect daily. For instance, while AC4 (at Naliendele and Nanyanga) and AC4/285 (at Nyangao) had appreciable quantities of cashew nuts at beginning of the season, AZA17 (at Naliendele) and AC10/220 (at Nanyanga and Nyangao) had no crop at that time. This on the other hand had cost implication, which was a typical problem that cashew growers usually incur.

In farmers' practice, cashew nut harvesting charges that are related to the time spent (that is, person-day or man-day) such as security guard, do not consider how much does each specific cashew genotype planted in the particular field yields per day. Implication of this observation is that, unless genotypes with dissimilar nut picking durations are grown in separate fields, part of the net revenue that could be earned from early maturing genotypes is unknowingly reduced due to the extended labour engagement required to take care of the late maturing genotypes.

5.2 Cashew nut yield

5.2.1 Cashew nut yield per day

From this study it was observed that there were significant variations ($P \leq 0.05$) for cashew nut yield per day among the clones within and across locations. For instance, while clone AC4/285 was consistently superior in producing highest quantities of cashew nut per day at Naliendele and Nyangao, AZA17 outperformed at Nanyanga. Those clones had the highest mean percentage kernel out-turns at the locations where they gave the highest yields. Similarly, the highest mean percentage kernel out-turn across locations was recorded on AC4/285, which also outperformed in mean yield per day. For this reason, the percentage kernel out-turns were regarded as an important parameter that probably contributed to the high cashew nut yield per day.

Based on sites, Naliendele was the most suitable location for harvesting high quantity of cashew nuts per day. The high cashew nut yields per day obtained at Naliendele were influenced by the high temperature experienced in such low altitude location as compared with others. This also suggests that low altitude areas are more suitable for cashew nut production than high altitude areas. However, selecting the best performing genotypes and locating them to the most suitable locations remains a necessary criterion for the best yield results. The clone AC4/285 was on average considered as the best clone for cashew nut yield per day across the three locations and specifically for Naliendele and Nyangao, while Nanyanga was the most conducive location for AZA17.

5.2.2 Cashew nut yield per season

Cashew clone AC/285 was the best yielding variety at Naliendele and Nyangao, while AC4 gave the highest yield at Nanyanga. The clone AC4/285 out-performed also across the three locations. The performance of these clones was positively correlated with yield per day. Since yield per day is a ratio of total nut yield to the number of days taken to pick the nuts, the superiority of these clones was possibly contributed by the ability of the clones to produce large quantities of nuts within a short time. The clones AC4/285 and AC4 are therefore potentially the topmost yielding clones at these specific locations. However, growing AC4/285 across the three sites can on average give the highest mean yields as compared with other clones.

Moreover, with respect to temperature and rainfall, the mean cashew nut yields of both the individual genotypes and overall mean yield of the seven clones were revealed to increase with increasing temperature and rainfall. For this reason, Naliendele site was the best location for optimum cashew nut production as compared with the rest of the sites. This was probably because of the high temperature and rainfall found at that location. The results concur with findings reported by NARI (2007) that cashew performs well in the locations with desirable high temperatures and rainfall.

5.3 Physical and nutritional nut quality

5.3.1 Physical nut quality

All physical qualities (nut weight, kernel weight, percentage kernel out-turn, nut length, nut and thickness) significantly varied ($P \leq 0.05$) among clones within and across the locations. Of these parameters, nut weight, kernel weight and percentage kernel out-turn are most important parameters in cashew nut grading, which are normally valued concurrently. On average, nuts collected from Nyangao recorded the highest overall mean weight. Therefore, Nyangao was the most suitable location for production of heavy weight cashew nuts. However, variability existed also within locations. This was evidenced at all sites. At Naliendele and Nanyanga, the outstanding clone was AC10/220, while at Nyangao the best clone was AC10. From the results it was found that the nut length and thickness were the factors that contributed to the high mean nut and kernel weights.

The best clone that performed well on mean percentage kernel out-turns at Naliendele and Nyangao was AC4/285, while AZA17 indicated the highest mean percentage kernel out-turn at Nanyanga. The possible reason for such high mean percentage kernel out-turns realized from this research was the small mean nut weights or sizes possessed by superior clones. This was because kernel filling of small nuts was higher than the large nuts. As the result the ratio of kernel weight to its raw nut weight was greater in small cashew nuts than in large nuts.

However, as far as physical raw cashew nut grading is concerned, commercially acceptable nuts must have at least 6 g, 1.5 g and 20 % nut weight, kernel weight and percentage kernel out-turn, respectively, (CRP, 2004/05, 2005/06, Anonymous). Simultaneous assessment of the nut weight, kernel weight and percentage kernel out-turn identified AC10/220 as the best performing clone at Naliendele and Nanyanga, while AC10 was the superior clone at Nyangao.

Despite the variations observed among clones at different locations, the results from this study have not shown a relationship between the environmental factors (temperature, rainfall and soil pH) and nut weight. Nevertheless, existence of this variability in nut weights among clones suggested the possibility for cashew breeders to select superior clones for specific and across locations.

The physical nut quality based on nut boiling time varied significantly ($P \leq 0.05$) among clones. Clone AZA2 had the shortest nut boiling time in all locations, which was positively correlated with kernel weight. This implied that small sized kernels require low power to boil. Physical observations showed that shells of AZA2 were relatively thinner than shells of other clones in all sites. Probably, such AZA2 shell thickness allowed the boiling water to be easily imbibed and thus made it possible to get boiled within the short time. Temperature, rainfall and soil pH did not show any significant effect on the nut boiling time suggesting that the environmental factors had little or no influence on the nut boiling time.

Although currently, nut boiling time is not used in raw cashew nut grading, the significant wide range of nut boiling time observed between AZA2 and the clones that took the longest time to boil have shown important implications on processed kernel quality. For instance, boiling together mixture of cashew nuts (e.g., AZA2 and AC4) that significantly varied in boiling time at Naliendele (ranging from 26 to 49 min) could at the end lead to either over heating small nuts or under heating the large nuts. According to Joyce Kayombo (personal communication, 2008), this could consequently result to obtaining undesirable kernel grades by either getting pieces (splits or butts) or scorched kernels, which normally fetch low prices. On the other hand, power consumption could be higher on AC4 than on AZA2. Hence, in order to obtain good quality kernels and have efficient power utilisation sorting the cashew nuts prior boiling should be carried out by size and/or genotype.

5.3.2 Nutritional quality of the cashew nut kernels

Significant variations ($P \leq 0.05$) among clones were observed in fat, protein, phosphorus, calcium, iron, zinc, copper, magnesium, potassium and sodium contents. With respect to fat content, the results at Naliendele showed the highest mean of this nutrient on AC10/220. The clone AC10 consistently outperformed at Nanyanga and Nyangao; it was again superior across the three locations. Investigations from this experiment indicated that the best performance of this clone in mean fat contents was highly correlated with the superiority in mean nut thickness. On the other hand, since there is a positive correlation between nut weight and nut thickness, the nut weight was probably one of the attributes which contributed to the high fat contents in the cashew kernels. Therefore, these parameters can be used to identify superior cashew genotype for fat contents.

Fat content in cashew kernels was revealed to vary with location. The study further indicated that there was an increasing level of fat content on AC10 with increasing altitude. The trend of fat content variations suggested that at the altitude beyond 334 m above sea level; where temperature could be much low, AC10 kernels could probably produce more fat than the ones obtained at Nanyanga (334 m above sea level). So far, the mean fat content recorded on this clone outperformed the ones reported by CBT (2007, Anonymous) and Wikipedia (2008) with respective values of 47 % and 43.85 %.

The results have shown that protein content in the cashew kernels at Naliendele and Nanyanga was highest on AC10, and on AC14 at Nyangao. Across the three locations, AC10 again showed the highest performance in protein content. The superiority in nut thickness and low cashew nut yields were some of the signs of high protein compositions in the clone AC10. Thus, cashew nut thickness and yielding ability can probably be used to indicate the protein content present in the nuts.

Mineral composition at Naliendele, Nanyanga and Nyangao were superior on the clones AC10/220, AC14 and AZA17, respectively. In these respective locations it was observed that while the clone AC10/220 was characterised with producing large nuts, AC14 showed the longest cashew nut picking duration. The results indicated that AC14 across the locations was the clone that contained the maximum mean quantity of minerals in the kernels, which might have contributed to long nut picking duration. The clone AZA17 had the smallest nut weight. This characteristic was probably associated with the quantity of mineral composition.

Based on the environmental factors, the results showed that composition of calcium, magnesium, potassium and sodium in the cashew kernels was high at the location where the soil pH was highest (Appendix 4). Calcium, magnesium, potassium and sodium are basic minerals that contribute to high soil pH. In view of this fact, it is possible that cashew genotypes grown at the high soil pH environment had too adequate and available quantities of such minerals to extract from the soil. These imply that it is possible to improve nutritional qualities of cashew kernels and the cashew nut yield through improvement of soil pH and fertility.

5.4 Genetic correlation between some traits in cashew at different locations

This study showed that the correlation strength or magnitude for various parameters varied with location. At Naliendele, very highly significant ($P \leq 0.001$) and positive correlations were observed between yield per season and yield per day ($r = 0.678^{***}$); nut weight and kernel weight ($r = 0.622^{***}$); nut weight and nut length ($r = 0.503^{***}$); kernel weight and nut length ($r = 0.690^{***}$). Similar relationships were found at Nanyanga, where correlations between yield per season and yield per day, nut weight and kernel weight, nut weight and nut length, also kernel weight and nut length were r = 0.787***, 0.711***, 0.784*** and 0.790***, respectively. Moreover, very highly significant and positive correlations between yield per season and yield per day (r = 0.868***); nut weight and kernel weight (r = 0.702***); nut weight and nut length (r = 0.679***); kernel weight and nut length (r = 0.632***) were observed at Nyangao. These positive correlations were important for cashew breeding. They gave the emphasis that for increased cashew nut yield per season a cashew clone must yield high quantity of nuts per day. They also indicated that improvement of nut weights or nut length would improve kernel weight. The relationships also meant that improvement of nut weight could be carried out through improving nut length.

The correlation analysis also showed highly significant and weak positive (r = 0.179**) relationship between protein and fat contents. The weak correlation suggested that cashew breeder could improve performance of cashew clones by increasing protein without affecting much the fat content.

The results further showed very highly significant ($P \leq 0.001$) but negative correlation between nut picking duration and yield per day at Naliendele (r = -0.679***) and Nyangao (r = -0.412***). This negative correlation was probably the effect of temperatures, which were decreasing with increasing altitude and consequently led to decreased rate of the cashew development. As the result of low temperature, the time for nut maturity was prolonged and the cashew trees dropped few mature nuts to harvest per day. These correlations concur with VUAT (2007), QG (2008) that low temperatures are not suitable for cashew. The other negative correlation was found between cashew yield per season and altitude where r = -0.495**. This also emphasized that low altitudes are best areas for optimum cashew nut production.

5.5 Associations among cashew nut yield influencing factors at Naliendele, Nanyanga and Nyangao

The path analysis was carried out in order to understand more on the causal effects contributing to increased cashew nut yield. At Naliendele, the strongest and significant direct effects on cashew nut yield were observed on nut yield per day (1.220) with genetic correlation of r = 0.667. The results indicated that this correlation coefficient could be even higher than 0.667, if not slightly offset by nut picking duration (-0.534). The other significant direct effect was the effect of nut picking duration on cashew nut yield (0.800). However, the magnitude of indirect effect of nut picking duration on cashew nut yield via nut yield per day (-0.828) was so large that the direct effect was offset; this resulted to a very small and negative correlation coefficient of nut picking duration (r = - 0.028). For this matter, the indirect effect of nut picking duration on cashew nut yield via nut yield per day was considered as important in influencing cashew nut yield (Singh and Chaudhary, 1977).

The study also found significant direct effects on cashew nut yield per day at Nanyanga (0.959) and Nyangao (1.051). It was further revealed from the path analysis that direct effects of nut picking duration contributed highly at Nanyanga (0.621) and Nyangao (0.533) on the cashew yield per season. Nevertheless, these were offset by nut yield per day with respective values of (-0.220) and (-0.433). Significant indirect effects of nut length via yield per day (-0.508) and nut weight via nut yield per day (-0.477) were found at Nanyanga. In addition to what was observed on each of the three locations, altitude was revealed to have significant direct effects, but negative on cashew nut yield (-0.499). In plant breeding, the implications of these results are: in order to maintain the yield, cashew breeders should pay more attention to those significant direct and indirect effect characters.

5.6 Simple regression analysis

On overall, cashew nut yield was negatively correlated with altitude (Fig.5). In addition, the regression model (Y = 4119 – 700.5x) used to estimate cashew nut yield (Fig. 10) indicated that the yield (Y) decrease with increasing altitude (x). It was demonstrated from the results that although yield performance among some cashew clones varied across the locations, the magnitudes of the cashew nut yield produced by every clone were found to decrease with increasing altitude. For example, at Naliendele location where the altitude is 102 m above sea level, AC10/220 produced higher yield than AC10. When yields of the same clones were evaluated at Nyangao (174 m above sea level) and Nanyanga (334 m above sea level) AC10 produced lower yields than AC10/220. However, the yields recorded on each clone at Naliendele were higher than the ones found at Nyangao. The lowest yields for each clone were observed at Nanyanga. On the other hand, the highest overall mean yield (3530.0 kg/ha) was obtained at the altitude of 102 m above sea level, while the lowest mean yield (2129.0 kg/ha) was obtained at the altitude of 334 m above sea level.

Logically, with increasing altitude, there is a decreasing temperature which is undesirable for cashew nut production. Therefore with such a trend of decreasing temperature, yield will be decreasing up to the point where no more economic yield will be obtained. The results from these observations stress that cashew breeders can improve cashew nut yield via identifying or developing superior cashew genotypes and locating them on suitable environments. With respect to temperature requirement, low altitudes locations such as Naliendele (102 m above sea level) are desirable as they provide high temperatures that are one of the important environmental factors for cashew nut yield.

5.7 Multiple regression analysis

Stepwise multiple regression model ($Y = -1395 + 39x_1 + 51x_2 - 89x_3 - 1x_4$), showed significant correlation between nut yield per season and yield per day (x_1), nut picking duration (x_2), nut weight (x_3) and altitude (x_4). The multiple regression model signified that the cashew nut yield can be improved through simultaneous improvement of the yield influencing factors. According to the model, yields per season (Y) increases with increasing yield per day and nut picking duration. This implied that if cashew breeders improve performance of a cashew genotype by overall mean yield (3530.0 kg/ha) was obtained at the altitude of 102 m above sea level, while the lowest mean yield (2129.0 kg/ha) was obtained at the altitude of 334 m above sea level.

Logically, with increasing altitude, there is a decreasing temperature which is undesirable for cashew nut production. Therefore with such a trend of decreasing temperature, yield will be decreasing up to the point where no more economic yield will be obtained. The results from these observations stress that cashew breeders can improve cashew nut yield via identifying or developing superior cashew genotypes and locating them on suitable environments. With respect to temperature requirement, low altitudes locations such as Naliendele (102 m above sea level) are desirable as they provide high temperatures that are one of the important environmental factors for cashew nut yield.

5.7 Multiple regression analysis

Stepwise multiple regression model ($Y = -1395 + 39x_1 + 51x_2 - 89x_3 - 1x_4$), showed significant correlation between nut yield per season and yield per day (x_1), nut picking duration (x_2), nut weight (x_3) and altitude (x_4). The multiple regression model signified that the cashew nut yield can be improved through simultaneous improvement of the yield influencing factors. According to the model, yields per season (Y) increases with increasing yield per day and nut picking duration. This implied that if cashew breeders improve performance of a cashew genotype by increasing yield per day, yield per season of the particular genotype could be increased.

The results also revealed that yield increases with decreasing nut weight and altitude. This indicated that cashew genotypes with relatively small nuts yield higher in low altitudes than if grown at high altitude. A typical genotype in this study was clone AC4/285. Thus, improvement of nut weight (size) and growing the improved genotype at low altitudes could also contribute to appreciably increased cashew yield. The stepwise multiple regression analysis revealed that 87.59 % of the total variation in cashew nut yield per season could be explained by variation in altitude. For this matter, altitude was revealed as most important factor which influences cashew nut yield. These results agreed with the observations that cashew performs well in low altitudes (NARI, 2007).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

Cashew clone AZA17 showed the shortest mean nut picking duration in all sites. On the other hand, clone AC4 showed earliness in crop maturity at Naliendele and Nanyanga, while clone AC4/285 matured earliest at Nyangao.

The cashew clone AC4/285 was the topmost cashew nut yielding variety across the three locations. Based on specific locations clone AC4/285 performed best at Naliendele and Nyangao, while clone AC4 was the leading clone in cashew nut yield at Nanyanga.

Across the locations, clone AC10 was superior in physical nut quality, fat and protein content. It was also superior at Nyangao and Nanyanga locations, while AC10/220 performed best at Naliendele. With respect to mineral composition clone AC14 was most superior across the sites. The outstanding clone in mineral composition at Naliendele was AC10/220.

Generally, this study has revealed that cashew clones superior in nutrient compositions are poor in cashew nut yield. The findings also found that there was genotype-environment interaction in cashew performance which had strong influence on nut picking duration, yield and quality. Cashew nut production tended to decrease as environmental temperature decreased.

6.2 RECOMMENDATIONS

For the shortest nut picking duration, it is recommended to grow AZA17 in all sites. Based on its high yielding potential across the locations, clone AC4/285 is recommended for planting in all experimental sites. On the other hand, clone AC4 is recommended for Nanyanga site where it performed best. However, for nut physical quality, fat and protein content, clone AC10 is recommended while AC14 is the best clone for mineral contents.

Since cashew nut yield is negatively correlated with nutrient compositions, the cashew growers are recommended to decide depending on the existing market: either to grow high nut yielding or high nutrient containing cashew genotypes.

Similar research works to evaluate more genotypes at different locations are recommended.

Suggestion is made for cashew breeders to evaluate chemical compositions of the cashew nut kernels and shells. This will enable both the cashew kernels consumers and CNSL processors to know what they expect to obtain from a given unit of raw cashew nuts. Finally, it is suggested to use the identified genotypes with desirable characters as parents in hybridization, so that the desirable traits can be incorporated in the new progenies.

REFERENCES

Acland, J.D. (1977). *East African Crops.* pp. 29-32, FAO and Longman.

AgricultureInformation.com (2008). *Cashew nut farming. Online Agriculture Business Community.* [http://www.agricultureinformation.com/forums/questions-answers/18383-cashewnut-farming.html] site visited on 10/03/2008.

Armstrong, W. P. (2004). *Brazil, Paradise & Cashew Nuts* [http://waynesword.palomar.edu/ecoph1.htm] site visited on 09/03/2008.

Azam-Ali, S. H. and Judge, E. C. (2002). *Cashew* [http://www.fao.org./AGA/ags/agsi/cashew/cashew.htm] site visited on 25/2/2007.

Bezerra, M. A., Lacerda, C. F., Filho, E. G., Abreu, C. E. B., and Prisco, J. T. *Brazilian Journal of Plant Physiology*; vol.19 no.4 Londrina Oct./Dec. 2007; [http://www.scielo.br/scielo.php? script=sci_arttext&pid=S1677-04202007000400012&lng=en..&nrm=iso] site visited on 20/05/2008.

Bradtke, B. (2007). *Cashew Growing: How to Grow Cashew Trees, Nuts and Apples.* Tropicalpermaculture. [http://www.tropicalpermaculture.com/growing-cashews.html]; site visited on 10/03/2008).

Business-Times (2003). *Cashewnut production in Tanzania* [http://www.tralac.org/scripts/content.php?] site visited on 23/04/2008.

Cashew.in (2006). *Cashewnut Recipe, Cashew Tree, Butter, Fruit, Nutrition* [http://www.cashew.in/] site visited on 09/03/2008.

CRFG (1995). *California Rare Fruit Growers: Fruit list.* [http://www.crfg.org/fg/xref/xref-a.html#anacardium_occidentale] site visited on 09/03/2008.

CRP (2004/05, 2005/06). *Cashew Research Program Annual Report.* Naliendele Agricultural Research Institute, Mtwara, Tanzania.

DCCD (2008). *About Cashew.* [http://dacnet.nic.in/cashewcocoa/tech.htm] site visited on 07/03/2008.

DoA (2000). *Cultivating Cashew Nuts.* [http://www.nda.agric.za/docs/cashews/cashew.htm] site visited on 07/03/2008.

Duke, J. A. (1983). *Handbook of Energy Crops: Anacardium occidentale* [http://www.hort.purdue.edu/newcrop/duke_energy/Anacardium_occidentale.html#Harvesting] site visited on 08/03/2008.

Eeuwijk van, F. A. and Elgersma, A. (2008). *Incorporating environmental information in an analysis of genotype by environment interaction for seed yield in perennial ryegrass.* [http://www.nature.com/hdy/journal/v70/n5/abs/hdy1199366a.html] site visited on 09/07/2008.

FAO (2006). *Crop Diversification in the Asia-Pacific Region.* Corporate Document Repository. [http://www.fao.org/docrep/003/x6906e/x6906e0h. htm#Top OfPage] site visited on 21/04/2008.

FAO (2008). *Minor oil crops.* [http://www.fao.org/docrep/X5043E/x5043E06.htm] site visited on 07/03/2008.

FAO (2004). *Cashew nut.* [http://www.uga.edu/fruit/cashew.html] site visited on 07/03/ 2008.

Foltan, H. and Ludders, P. (1995). Flowering, Fruit Set, and Genotype Compatibility in Cashew; *Vereinigung fur Angewandte Botanik, Gottingen;* Vol 69; pp 215-220.

GDV (2008). *Cashew nuts.* Transport Information Service. [http://www.tis-gdv.de/tise/ware/nuesse/cashew/cashew.htm] site visited on 07/03/2008.

Gilbert, R. A., Shine, J. M., Miller, J. D., Rice R. W., Rainbolt C. R. (2007). *The effect of genotype, environment and time of harvest on sugarcane yields in Florida, USA.* [http://cat.inist.fr/?aModele=afficheN&cpsidt=17403817] site visited on 09/07/2008.

Google (2007). *Cashews: All You Ever Wanted to Know.* [http://organiccashewnuts. com/learnmore.htm#uses] site visited on 10/03/2008.

Gonçalves, P. S., Bortoletto, N., Martins, A. L. M., Costa, R. B. and Gallo, P. B. (2003). *Genotype-environment interaction and phenotypic stability for girth growth and rubber yield of Hevea clones in São Paulo State, Brazil.* [http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1415-4757200300 0400007&lng=pt&nrm=isso] site visited on 09/07/2008.

Groom, M. J., Maffe, G. K. and Carroll, C. R. (2006). *Principles of Conservation Biology*, 3rd ed; Sinauer Associates, Inc. Publishers; Sunderland, Massachusetts U.S.A. pp 346.

JAC Exports and Exports & Imports Pvt. Ltd (2007). *Agri Products Vietnam – Cashew.* [http://www.jacexim.com/products_Vietnam.html]. site visited on 10/03/2008.

Kasuga, L. J. F. (2003). *Adoption of Improved Cashew (Anacardium occidentale L.) by Smallholders in South Eastern Tanzania*; PhD Thesis; Department of Agricultural Botany, School of Plant Sciences, Whitenights, The University Of Reading, UK.

Keralaagriculture (2008). *Cashew.* [http://www.keralaagriculture.gov.in/htmle/bankableagriprojects/ph%5Ccashew.htm] site visited on 10/03/2008.

Kohler, J. (1998). *Raw cashew nuts - Are they raw?* [http://www.living-foods.com/articles/rawcashew.html] site visited on 09/03/2008.

Loan, L. T., Phuong, D. H. and Hung, V. (2006). *Cashew nuts supply chains in Vietnam: A case study in Dak Nong and Binh Phuoc provinces, Vietnam.* [www.socialforestry.org.vn/Document/DocumentEn/Cashew%20nut%20Vietnam.En%20(Full%20document).pdf] site visited on 21/07/2008.

Luat, N. V. (2001). *Crop Diversification in Viet Nam* [http://www.fao.org/docrep/003/x6906e/x6906e0d.htm] site visited on 21/04/ 2008.

MBendi (2004). *An MBendi Profile: Africa: Agriculture, Forestry, and Fishing: Fruit and Nut Growers - Information for Africa.* [http://www.mbendi.co.za/indy/agff/frut/af/p0005.htm]; Site visited on 09/03/2008.

Martin, P. J., C. P. Topper, R. A. Bashiru, F. Boma, D. De Waal, H. C. Harries, L. J. Kasuga , N. Katanila, L. P. Kikoka, R. Lamboll, A. C. Madisson, A. E Majule, P. A. Masawe, K. J. K. Millanzi, N. Q. Nathaniels, S. H. Shomari, M. E. Sijaona and T. Stathers, 1997. *Cashew nut production in Tanzania. Constraints and Progress through integrated crop management. Crop Protection* 1997. ~~Vol 16 Number 1~~. 16(1): — - —

Masawe, P. A. L. (2006). *Tanzania Cashew Cultivars: Selected Clones*; Cashew Research Programme, Naliendele Agricultural Research Institute, Mtwara, Tanzania.

Meyers, K. (2008). *Organic cashewnuts.* [http://www.organiccashewnuts.com/ cashewbenefits.htm] site visited on 20/05/2008.

Mirzawan, P. D. N., Cooper, M. and Hogarth D. M. (1993).*The impact of genotype multiply environment interactions for sugar yield on the use of indirect selection in southern Queensland.* [http://www.publish.csiro.au/paper/EA99 30629.htm] site visited on 09/07/2008.

Moncur, M. W. and Wait, A. J. (1986). *Pollination Biology of cashew in Northern Territory of Australia.* [http://www.publish.csiro.au/paper/AR9901101.html] site visited on 05/07/2008.

Morton, J. (1987). *Cashew Apple. Fruits of warm climates.* [http://www.hort.purdue.edu/newcrop/morton/cashew_apple.html] site visited on 09/03/2008.

Mwangu, P. (2007). *Cashew Nuts Neglected Despite its Economic Importance.* SUNDAY OBSERVER. [http://www.ippmedia.com/ipp/observer/2007/10/28/101334.html] site visited on 21/04/2008.

Nandi, B. K. (2005). *Cashew Nut Nutritional Aspects.* [http://fao.org/docrep/005/ac45e0b.htm] site visited on 10/07/2007.

NARI (2006). Cashew nut Production *(Kilimo Bora cha Korosho)*; ARI Naliendele, Mradi Shirikishi na Maendeleo ya Kilimo na Uwezeshaji (PADEP); Ukulima wa Kisasa Printing Press, Dar es Salaam; pp 3, 45.

NARI (2007). *Cashewnut Production Handbook*; Premadasa Colour Scan (T) Ltd, Dar-es-Salaam; pp 2, 5.

NLU and TNU (2006). *Cashew Nut Supply Chains In Vietnam; A Case Study In Dak Nong and Binh Phuoc Provinces of Vietnam.* [www.socialforestry.org.vn/.../CasestudyonCashewnutsupplychainsinVietnam.pdf] site visited on 08/03/2008.

Nutsonline (2008). *Cashews – Including Roasted cashews, Salted, Chocolate and more...* [http://www.nutsonline.com/nuts/cashews/] site visited on 10/03/2008.

O'Farrel, P., Blaikie, S. and Chako, E. [http://www.rirdc.gov.au/pub/handbook/cashew.html] site visited on 10/03/2008.

Ohler, J. G. (1979). *Cashew*; Koninklijk Instituut voor de Trpen, Amsterdam; pp 191.

Onsongo, M. (2006). SDA Foreign Agricultural Service. GAIN Report Kenya Tree Number: KE6001. [http://www.tralac.org/scripts/content.php?id=1925] site visited on 10/03/2008.

Padi, F. K. (2007). *Genotype × environment interaction and yield stability in a cowpea-based cropping system.* [http://www.springerlink.com/content/65877j2280805616/] site visited on 09/07/2008.

Premier (2008). *Cashew nuts* [www.grolink.se/epopa/Publications/Proj-folders/Premier-Cashew-Industries.pdf] site visited on 10/03/2008.

QG (2008). *Growing cashews*. [http://www2.dpi.qld.gov.au/horticulture/5343.html#2]; Site visited on 09/03/2008.

Rao, M. and Hassan, V. (1957). *Tree Fruits & Nuts and Exotic Tree fruits and Nuts*. [http://www.gears.tucson.ars.ag.gov/book/chap5/cashew.html] site visited on 07/07/2008.

Rawcreation Ltd & Shazzie (2008). *Raw cashew nuts*. [http://www.detoxyourworld. com/acatalog/cashews.html] site visited on 08/03/2008.

Reuben, S. O. W. M., Mulungu, L. S., Nchimbi-Msolla, S., Misangu, R. N., Mbilinyi, L. B. and Macha, (M. 1998). Performance of nine exotic and local onion (Allium cepa L.) genotypes grown under dry season tropical condition at Morogoro, Tanzania: 2. Path coefficient analysis. *South African Journal of Science*, vol. 94. September 1998. 454 - 455pp.

Rieger (2006). *Cashew - Anacardium occident.* [http://www.uga.edu/fruit/cashew. html] site visited on 07/03/ 2008.

Rocha, A. (2006). *Cashew Nut Harvest Almost Doubles in Brazil. Most of It Goes to the US.* [http://www.brazzilmag.com/content/view/7414/54/] site visited on 07/03/ 2008.

SADOCC (2003). *Tanzania loses billions in raw cashew exports*. [http://www. sadocc.at/news/2003-235.shtml] site visited on 21/03/2008.

Simmonds, N. W. and Smartt, J (1999). *Principles of Crop Imrovement.* Blackwell Science Ltd, 1999.

Singh, K. B. and Chaudhary, B. D. (1977). *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers. New Delhi-India, 304p.

Taylor, L. (2005). *Database Entry for Cajueiro – Anacardium occidentale.* Raintree Nutrion – Tropical Plant Database [http://www.rain-tree.com/cajueiro.htm] site visited on 09/03/2008.

TFM (2008). *TFM: What's New - Online Exhibit* [http://www.food museum.com/index.html] site visited on 01/03/2008.

TGMF (2008). *WHFoods: Cashews.* [http://www.whfoods.org/genpage.php?tname= foodspice&dbid=98]; site visited on 18/04/2008.

TNF (2008). *Kitchen: Interesting Facts: Cashews.* [http://www.thenutfactory.com/ kitchen/facts/facts-cashews.html] site visited on 07/03/2008.

VUAT (2007). *Cashew Crop Management: Climate and Soil.* [http://www. vuatkerala.org/static/eng/advisory/agri/Cashew/climate,%20soil.htm] site visited on 10/03/2008.

VUAT (2008). *Cashew Harvesting and Storage* [http://www.vuatkerala.org/static/eng/advisory/agri/Cashew/Harvesting%20and%20storage.htm] site visited on 10/03/2008.

VUAT (2007). *Cashew origin.* [http://www.vuatkerala.org/static/eng/advisory/agri/Cashew/origin.htm] site visited on 10/03/2008.

VUAT (2008). *Cashew – Products and Standards.* [http://www.vuatkerala.org/static/eng/advisory/agri/Cashew/Products.htm]; site visited on 10/03/2008.

Wakabi, W. (2004). *African Cashews to Indian Factories: How the Continent Exports its Profits and Jobs: East African Business* [http://organiccashewnuts.com/cashewafricajobsarticle.htm] site visited on 20/05/2008.

Wamatu, J. N. and Thomas, E. (2002). *The Influence of Genotype-Environment Interaction on the Grain Yields of 10 Pigeonpea Cultivars Grown in Kenya [http://www.ingenta*connect.com/content/bsc/jac/2002/00000188/00000001/art00005?crawler=true] site visited on 09/07/2008.

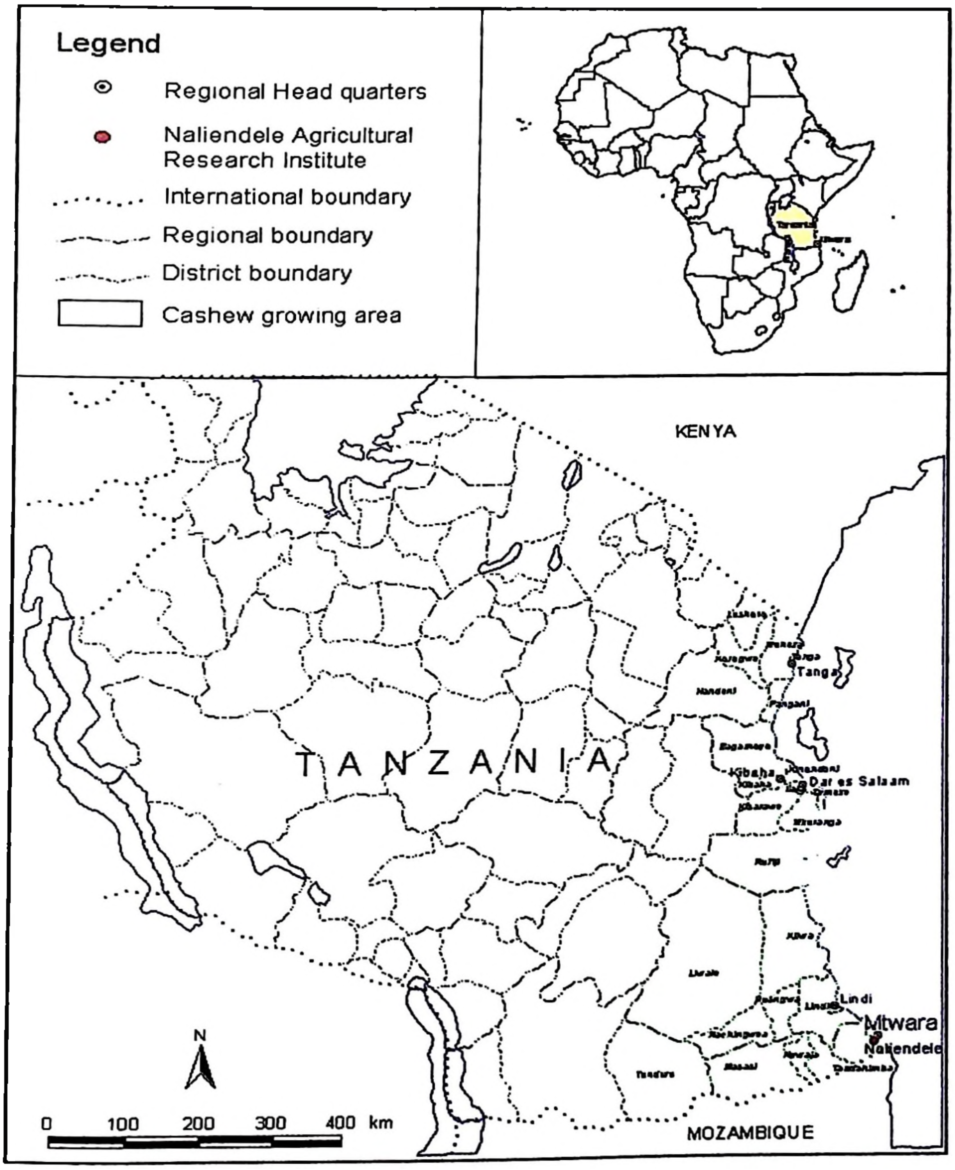
Wikipedia (2008). *Cashew.* [http://en.wikipedia.org/wiki/Cashew] site visited on 09/03/2008.

Woodroof, J. G. (1979). *Tree Nuts*; 2nd ed; The AVI Plishing Company, Inc. Westport, Connecticut; pp 219 – 220.

Yan, W and Hunt, L.A. (2000). *Interpretation of Genotype × Environment Interaction for Winter Wheat Yield in Ontario* [http://crop.scijournals.org/cgi/content/full/41/1/19] site visited on 09/07/2008.

APPENDICES

Appendix 1. Main cashew producing areas in Tanzania



Appendix 2. Analytical model:

Statistical model was: $Y_{ijk} = \mu + \rho_k + \alpha_i + \delta_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

Where:

- Y_{ijk} is the observed value for the k^{th} replicate of the i^{th} level of factor A and the j^{th} level of factor B (where i = 1 to a, j = 1 to b and k = 1 to r)
- μ is the general mean
- ρ_k is the block effect for the k^{th} block
- α_i is the effect of the i^{th} level of factor A (site)
- δ_{ik} is the whole plot random error effect, for the i^{th}, k^{th} combination of block and factor A
- β_j is the effect for the j^{th} level of factor B (clone)
- $\alpha\beta_{ij}$ is the interaction effect of the i^{th} level of factor A with the j^{th} level of factor B
- ε_{ijk} is the subplot random error effect associated with the Y_{ijk} subplot unit.

Appendix 3. Rainfall and temperature data recorded at Naliendele, Nanyanga and Nyangao locations from January – December 2007

Month	Rainfall (mm)			Temperature (^oC)		
	Naliendele	Nanyanga	Nyangao	Naliendele	Nanyanga	Nyangao
Jan	65.0	237.2	75.5	27.5	25.4	26.6
Feb	232.5	153.5	162.3	26.9	26.0	25.0
March	124.6	75.5	121.6	27.5	25.1	26.5
April	197.6	58.5	177.0	27.2	25.3	26.3
May	10.4	00.0	11.8	26.5	24.5	25.0
June	05.7	00.0	00.0	25.1	23.0	24.2
July	16.7	04.0	15.5	24.8	22.9	23.8
Aug	14.6	00.0	40.3	25.3	23.0	24.2
Sept	11.9	30.8	37.0	25.9	24.2	24.0
Oct	35.5	42.4	36.9	26.5	24.7	25.5
Nov	11.9	97.0	11.4	27.2	25.1	26.1
Dec	67.0	34.2	73.2	28.2	26.2	25.4
	793.4	**733.1**	**762.5**	**26.5**	**24.6**	**25.2**

Appendix 4. Soil pH levels measured at three experimental locations

Location	pH level
Naliendele	5.6
Nanyanga	5.7
Nyangao	6.8

Appendix 5. Analysis of variance for cashew nut picking duration, yield and physical nut quality at Naliendele

Source	df	Mean squares								
		Picking duration	Yield/ha/ season	Yield/ha/ day	Nut weight	Kernel weight	Kernel out-turn	Nut length	Nut thickness	Nut boiling time
Rep	3	157	1621077.8	1075.6	1.0	0.04	3.0	0.08**	0.01	3.5**
Clone	6	1709.3**	5115438.5**	8083.6**	13.6**	0.94**	46.3**	0.52**	0.30**	617.6**
Rep× Clone	18	53.3	399679	592.7	0.5	0.22**	4.8**	0.05**	0.01	11.9**
Error	46	76.2	880624	543.8	0.4	0.06	1.97	0.02	0.01	0.7

** $P \leq 0.01$

Appendix 6. Analysis of variance for cashew nut picking duration, yield and physical nut quality at Nanyanga

		Mean squares								
Source	df	Picking duration	Yield/ha/ season	Yield/ha/ day	Nut weight	Kernel weight	Kernel out-turn	Nut length	Nut thickness	Nut boiling time
Rep	3	263.2**	184819.0	76	0.7	0.1	1.1	0.03	0.03	3.6**
Clone	6	194.9**	2022421.8**	655.5**	9.6**	0.7**	13.0**	0.35**	0.24**	317.1**
Rep× Clone	18	104.2	209144.3	37.7	0.5	0.1	1.9	0.02	0.02	6.7**
Error	30	70.3	344723.4	8.5	0.4	0.1	4.7	0.01	0.01	0.5

** $P \leq 0.01$

Appendix 7. Analysis of variance for cashew nut picking duration, yield and physical nut quality at Nyangao

Source	df	Mean squares								
		Picking duration	Yield/ha/ season	Yield/ha/ day	Nut weight	Kernel weight	Kernel out-turn	Nut length	Nut thickness	Nut boiling time
Rep	3	162.4	469821.1	107	0.8	0.2**	0.8	0.01	0.01	2.6**
Clone	6	198.7*	2631319.8**	979.3**	19.0**	0.8**	17.4**	0.15**	0.14**	297.8**
Rep× Clone	18	49	562169	202.9**	0.8	0.04	4.9	0.01	0.03	2.4**
Error	32	82.5	409469.9	9.66	0.7	0.04	2.9	1.002	4.002	8.001

* $P \leq 0.05$; ** $P \leq 0.01$

Appendix 8. Analysis of variance for fat, protein and mineral contents at Naliendele

Source	df	Mean squares									
		Fat (%)	Protein (%)	P (%)	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mg (%)	K (%)	Na (mg/kg)
Rep	3	0.56**	0.83**	2.3805	153	0.0041	0.0015	1.2105	2.5505	3.1105	0.0003
Clone	6	16.33**	13.87**	0.002**	25117.8**	355.98**	42.2**	47.18**	0.0019**	0.033 **	1968.3**
Rep× Clone	18	0.20**	0.85**	1.4105	131.5	0.00851	0.0011	1.3905	1.6905	2.3205	0.00026
Error	46	0.08	0.002	8.6205	399.7	0.03757	0.0061	9.1705	8.305	7.1705	0.00044

** $P \leq 0.01$

Appendix 9. Analysis of variance for fat, protein and mineral contents at Nanyanga

Source	df	Mean squares									
		Fat (%)	Protein (%)	P (%)	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mg (%)	K (%)	Na (mg/kg)
Rep	3	1.0**	5.1**	5.2505	0.002	0.00025	0.00017	5.6605	0.000025	3.1105	0.0005
Clone	6	85.5**	4.6**	0.006**	162136.4**	4289.9**	30.4**	12.97**	0.0034**	0.0327**	3434.6**
Rep× Clone	18	0.7	3.0**	2.4605	0.004	0.00026	0.00001	1.7105	4.8105	2.3205	0.00048
Error	30	0.2	0.003	6.8305	0.008	0.00106	0.00007	6.6705	0.00006	7.1705	0.00158

** $P \leq 0.01$

Appendix 10. Analysis of variance for fat, protein and mineral contents at Nyangao

		Mean squares									
Source	df	Fat (%)	Protein (%)	P (%)	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mg (%)	K (%)	Na (mg/kg)
Rep	3	0.2	4.3**	2.6205	0	0.002	0.000002	3.0005	1.8306	2.9605	0.001
Clone	6	22.5**	4.9**	0.005**	1122204.9**	1238.04**	39.9**	21.5**	0.002**	0.1**	4256.4**
Rep× Clone	18	0.1	2.9**	3.5106	0.001	0.001	0.000013	5.0006	8.6606	1.6605	0.001
Error	32	0.1	0.0003	2.5505	0.003	0.002	0.00003	3.0005	3.2805	3.2805	0.002

** $P \leq 0.01$

Appendix 11. Combined analysis of variance for cashew nut picking duration, yield and physical nut quality at Naliendele, Nanyanga and Nyangao

Source	df	Mean squares								
		Picking duration	Yield/ha/ season	Yield/ha/ day	Nut weight	Kernel weight	Kernel out-turn	Nut length	Nut thickness	Nut boiling time
Location	2	3495.8**	35822017.6**	40073.3**	23.3**	0.1	71.5**	0.43**	0.15**	204.0**
Rep	3	369.5**	1161106	759.8*	1.3	0.1	0.91	3.0002	3.0002	2.4600
Loc× Rep	6	195.7**	531545.6	292.6	0.7	0.1	2.1	0.03	0.01	4.21
Clone	6	1049.1**	8002453.6**	6377.4**	41.0**	2.0**	68.2**	8.3001	6.0001	1002.0**
Clone× Loc	12	503.7**	828417.8	1413.2**	2.4**	0.2	5	0.08**	3.0002	1.0902
Error	162	73.9	524884.5	281.8	0.5	0.1	3.3	0.016	0.019	2.8

** $P \leq 0.01$; * $P \leq 0.05$

Appendix 12. Combined analysis of variance for fat, protein and mineral contents at Naliendele, Nanyanga and Nyangao

Source	df	Mean squares									
		Fat (%)	Protein (%)	P (%)	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mg (%)	K (%)	Na (mg/kg)
Location	2	41.0**	32.8**	0.08**	480168.3**	7925.6**	15.3**	59.3**	0.01**	1.1401	2728.9**
Rep	3	0.3	1.8	1.9105	30.4	0.0007	0.0006	0.000008	1.7905	12.9	0.0002
Loc× Rep	6	1.2**	3.9**	2.8205	32	0.00187	0.0002	4.0005	9.8306	1.4101	0.0007
Clone	6	72.3**	19.9**	0.004 **	700490.8**	1099.7**	33.04**	54.6**	0.003**	11.9	2680.1**
Clone× Loc	12	33.3**	3.3**	0.005**	367508.4**	2622.7**	41.0**	11.002**	0.003**	15	3703.4**
Error	162	0.2	0.8	4.6905	128.1	0.01	0.002	0.00005	4.9305	19.6	0.001

** $P \leq 0.01$

Appendix 13. Cashew nut yield and nutrient compositions in cashew nut kernels across three locations

Clone	Yield (rank)	Fat and protein contents (rank)	Mineral contents (rank)
AC4/285	1	7	6
AC4	2	6	7
AZA2	3	4	4
AZA17	4	3	3
AC14	5	5	1
AC10/220	6	2	2
AC10	7	1	5

Note: Rank 1 and 7 stands for the highest and the lowest values, respectively.

Appendix 14. Multiple regressions statistics for estimating cashew nut yield through influence of altitude: Summary of stepwise selection

	Variables	Parameter estimate	Partial R-Square	Model R-Square	F Value	Pr > F
	Intercept	-1395				
1	Yield/day	39	0.6381	0.6381	335.04	<.0001
2	Nut picking duration	51	0.2247	0.8628	309.53	<.0001
3	Nut weight	-89	0.0104	0.8732	15.34	0.0001
4	Altitude	-1	0.0027	0.8759	4.11	0.0440