GENOTYPE x ENVIRONMENT INTERACTION ON PERFORMANCE OF SELECTED CASHEW (*Anacardium occidentale* L.) HYBRIDS IN TANZANIA

JOACHIM P. N. MADENI

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.

2016

ABSTRACT

Cashew (*Anacardium occidentale* L.) is an important export crop in a number of tropical countries and is the main cash crop and the leading source of income for over 300,000 households in Southern and Eastern Tanzania. Farmers still, however use unimproved varieties, which account for low yields. Thirty cashew genotypes were evaluated to assess genetic variability for higher yield and its components at two locations (Nachingwea and Chambezi) in the Southern and Eastern zones of Tanzania, respectively, during the 2014/2015 production season. The experiment was laid out in Randomized Complete Block Design with three replications. Genotype x location interaction was significant for all agronomic characters studied and all nutritional characters except Calcium and Sodium contents, indicating influence of the environment on the expression of most traits. High yielding genotypes with broad adaptation and some with specific adaptation were identified. Of these, H3, H5, H6, H15, H16, H22, H23, H24, H26, H27 and H29 were adapted to varying environments. In the contrary, high yielding unstable hybrids H2, H4, H7, H18, H19, H25 and H30 were more suitable for Nachingwea site while H1, H8, H10, H11, H13 and H17 were more favourable for Chambezi site. H22, H5 and H24 were identified as the best in stability, yield with good agronomic and nutritional attributes and tolerance to blight disease. Growing for nutritional quality, hybrid H1 was more favorable in a number of variables such as protein, fat, potassium, copper, iron, zinc and vitamin C. Among the least stable hybrids in yield, H4, H8, H17, H11, H18 and H30 had high yields with good agronomic and nutritional traits. Others, H28, H12 and H9 appeared to be stable but recorded low yields. Therefore crosses between these two groups will combine stability and yield in the same background.

DECLARATION

I, JOACHIM P. N. MADENI do hereby declare to the Senate of the Sokoine University of Agriculture (SUA) that the work presented here is my original work and has not been submitted for a higher degree in any other University.

______________________________ __________________

Joachim P. N. Madeni Date

(MSc. Crop Science Candidate)

The above declaration is confirmed

______________________________ __________________

Prof. Reuben S. O. W. M Date

(Supervisor)

______________________________ __________________

Prof. Msuya D. G. Date

(Supervisor)

COPYRIGHT

AKNOWLEDGEMENTS

In the first place, I would like to thank God the Almighty who gave me life and grace to venture into this undertaking. To Him, all praise is due.

Secondly, my special thanks are due to my parents Mr. Paul Madeni and Ms. Suzana Bukwimba who raised me with love and dedication.

I thank the Government of the United Republic of Tanzania, through the Department of Research and Development; Tanzania Commission for Science and Technology for sponsoring me in my study.

This work has been accomplished under the inspiring supervision of Professor S.O.W.M Reuben and Professor D. G. Msuya from proposal development, all the way to the production of this dissertation. I would like to acknowledge their valuable comments and useful recommendations without which this study would not have reached this far.

I would like also to extend my sincere thanks to Naliendele Agricultural Research Institute staff especially in Cashew Breeding Department for giving me the breeding materials and for their constructive advice. Special thanks should go also to Professor Peter Masawe, Dr Elly Kafiriti, Dr. Omary Mponda, Mr Fortunus Kapinga, Ms Stella Mfune, Mr Zabron Ngamba, Mr Dadili Majune, Mr Nene Wilson, just to mention a few, for their advice and moral support to me.

DEDICATION

This work is dedicated to my wife Ester Sylivester Kachwele, my daughter Gloria and my son Benedict Joachim Madeni who have remained a source of motivation for my academic achievements. They, most of the time, had to do without my presence but remained supportive to me.

TABLE OF CONTENTS

ABSTRACT ii

DECLARATION iii

COPYRIGHT iv

AKNOWLEDGEMENTS v

DEDICATION vi

TABLE OF CONTENTS vii

LIST OF TABLES xii

LIST OF FIGURES xiv

LIST OF APPENDICES xv

LIST OF ABBREVIATIONS xvi

CHAPTER ONE 1

1.0 INTRODUCTION 1

1.1 Background Information 1

1.2 Problem Statement and Justification 3

1.3 Objectives 4

1.3.1 Overall objective 4

1.3.2 Specific objectives 4

CHAPTER TWO 5

2.0 LITERATURE REVIEW 5

2.1 Origin and Distribution of Cashew 5

2.2 Trend in Cashew Production 6

2.3 Production Constraints 6

2.4 Uses of Cashew 8

2.5 Nutrition Quality of Cashew 9

2.6 Botanical Descriptions 10

2.7 Yield Components 12

2.8 Yield Potential 13

2.9 Genotype x Environment Interaction 14

2.10 Stability Parameter 15

2.11 Path Coefficient Analysis 16

CHAPTER THREE 17

3.0 MATERIALS AND METHODS 17

3.1 Experimental Sites and Materials 17

3.2 Methods 17

3.3 Data Collection 17

3.3.1 Yield 17

3.3.2 Nut weight 18

3.3.3 Kernel weight 18

3.3.4 Percentage kernel out-turn 18

3.3.5 Nut number per tree 18

3.3.6 Nut per panicle 19

3.3.7 Leaf and nut blight diseases 19

3.3.8 Fat content determination 19

3.3.9 Protein content determination 20

3.3.10 Mineral determination 21

3.3.11 Calcium, magnesium, potassium and sodium 21

3.3.12 Iron, zinc and copper 22
3.3.13 Vitamins C determination 22
3.4 Data Analysis 22
3.4.1 Analysis of variance 23
3.4.2 Path coefficient analysis 23

CHAPTER FOUR 27
4.0 RESULTS 27
4.1 General Profile of the Study Area 27
4.2 ANOVA for the Studied Agronomic Variables 27
4.3 Effect of Hybrids on Yield and Yield Components of Cashew 30
4.3.1 Yield 30
4.3.2 Nut weight 34
4.3.3 Nuts per tree 35
4.3.4 Nuts per panicle 35
4.3.5 Kernel weight 34
4.3.6 Percentage out turn 37
4.3.7 Cashew leaf and nut blight disease 34
4.4 Effect of Location 38
4.5 Effect of Genotype x Location on the studied agronomic variables 38
4.6 Nutritional Characteristics of the Studied Hybrids 40
4.6.1 ANOVA for the studied nutritional variables 40
4.6.2 Genotypic effects 42
4.6.2.1 Crude protein 42
4.6.2.2 Fat 42

4.6.2.3 Potassium 46

4.6.2.4 Magnesium 46

4.6.2.5 Copper 46

4.6.2.6 Iron 47

4.6.2.7 Vitamin C 47

4.6.2.8 Zinc 48

4.6.3 Effect of location on the studied nutritional variables 46

4.6.4 Effect of Genotype x Location on the nutritional variables 49

4.7 Genetic Correlations between Cashew Yield Components at Nachingwea and Chambezi 50

4.8 Path Analysis 56

4.8.1 Associations among cashew yield influencing components at Nachingwea and Chambezi 56

4.8.1.1 Associations at Nachingwea 56

4.8.1.2 Associations at Chambezi 58

4.8.1.3 Associations of cashew yield components in combined analysis 61

4.9 Stability Analysis 63

CHAPTER FIVE 66

5.0 DISCUSSION 66

5.1 Performance of Cashew Hybrids in the Locations 66

5.1.1 Cashew yield 66

5.1.2 Nut weight 67

5.1.3 Nuts per tree 68

5.1.4 Nuts per panicle 69

5.1.5 Kernel weight 69

5.1.6 Percentage outturn 69

5.2 Nutritional Quality Characteristics of the Studied Cashew Hybrids 70

5.2.1 Percentage Protein 70

5.2.2 Percentage Fat 71

5.2.3 Potassium 71

5.2.4 Magnesium content 71

5.2.5 Copper content 72

5.2.6 Iron content 73

5.2.7 Zinc content 73

5.2.8 Vitamin C 74

5.3 Cashew Leaf and nut Blight Disease Reactions 74

5.4 Genetic Correlations 75

5.5 Overall aassociations among Cashew Yield and its Components 77

5.6 Stability for Yield and Yield Components for the Studied Hybrids 78

CHAPTER SIX 80

6.0 CONCLUSIONS AND RECOMMENDATIONS 80

6.1 Conclusions 80

6.2 Recommendations 81

REFERENCES 83

APPENDICES 92

LIST OF TABLES

Table 1: Leading cashew producers (tons) worldwide 6

Table 2: Nutritional contents of cashew nut (Nutrition value per 100 g) 9

Table 3: Analysis of variance for studied cashew yield, yield components and blight disease at Nachingwea, Chambezi and in combined analysis 29

Table 4: Means for yield, yield components and blight disease of cashew hybrids at Nachingwea 31

Table 5: Mean for yield, yield components and blight disease of cashew hybrids at Chambezi 32

Table 6: Combined analysis data averages of yield, yield components and blight disease of cashew hybrids grown at Nachingwea and Chambezi 33

Table 7: Location effects for cashew yield and yield components 38

Table 8: Analysis of variance for studied cashew nutritional variables at Nachingwea, Chambezi and in combined analysis 41

Table 9: Nutritional composition and quality of cashew nuts hybrids at Nachingwea 43

Table 10: Nutritional composition and quality of cashew nuts hybrids at Chambezi 44

Table 11: Nutritional composition and quality of cashew nuts hybrids in combined analysis 45

Table 12: Effects of location on studied nutritional variables 49

Table 13: Correlations for yield and yield components of cashew hybrids at Nachingwea 53

Table 14: Correlations for yield and yield components of cashew hybrids at Chambezi site 54

Table 15: Correlations for yield and yield components of cashew hybrids in combined analysis 55

Table 16: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield at Nachingwea .. 56

Table 17: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield at Chambezi 59

Table 18: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield in combined analysis 62

Table 19: Stability results of yield and yield components by Wricke's ecovalence (Wi)... 64

LIST OF FIGURES

Figure 1: Path diagram showing direct and indirect effects on yield and yield components.. 24

Figure 2: Path diagram showing relationships between yield and yield components of cashew at Nachingwea.. 57

Figure 3: Path diagram showing relationships between yield and yield components of cashew at Chambezi. 60

Figure4: Path diagram showing relationships between yield and yield components of cashew under combined analysis. 62

LIST OF APPENDICES

Appendix 1: Soil characteristics of the experimental soils at Nachingwea and Chambezi 92

Appendix 2: Meteorological data 92

Appendix 3: Path coefficients for Nachingwea of cashew hybrids yield influencing variables 93

Appendix 4: Path coefficients for Chambezi of cashew hybrids yield influencing variables 95

Appendix 5: Path coefficients for combined sites of cashew hybrids yield influencing variables 97

LIST OF ABBREVIATIONS AND SYMBOLS

≤	Less than or equal to
μ	Micro
%	Percentage
AC4	Anacardium Ceylon 4
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
^{o}C	degree Celsius
Ca	Calcium
CBT	Cashew nut Board of Tanzania
CLNBD	Cashew Leaf and Nut Blight Disease
cm	Centimeter
CNSL	Cashew Nut Shell Liquid
CP	Crude Protein
Cu	Copper
CV	Coefficient of Variation
DF	Degree of freedom
ECI	Ebony Consulting International
FAO	Food and Agricultural Organization
Fe	Iron
G x E	Genotype by Environment Interaction
H	Hybrid
HCl	Hydrochloric Acid

H_2O	Water
K	Potassium
Kcal	Kilocalorie
kg	Kilogram
KNWT	Kernel weight
LSD	Least Significant Difference
M	Molar
MAFC	Ministry of Agriculture Food Security and Cooperatives
Mg	Magnesium
mm	Millimeter
N	Nitrogen
Na	Sodium
NARI	Naliendele Agricultural Research Institute
nm	Nanometers
NTPCL	Nuts per panicle
NTPT	Nuts per tree
NTWT	Nut weight
OT	Out turn
PASS	Private Agricultural Sector Support
pH	Potential of Hydrogen
ppm	Parts per million
RCBD	Randomized Complete Block Design
Rep	Replication
RDA	Recommended Dietary Allowance

S.E	Standard Error
UH	University of Hawaii
USDA	United States Department of Agriculture
Wi	Wricke's ecovalence
YLD	Yield
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Cashew (*Anacardium occidentale* Linn) is a drought resistant evergreen perennial tree plant with dense foliage that can grow as high as 15 meters or more (Aliyu, 2012). It is a member of *Anacardiaceae* family with about 60 genera and 400 species (Ohler, 1979). It is known to have originated from South America and it was introduced in East Africa in the 16th century by the Portuguese (Woodroof, 1979).

Cashew has been one of the most important export crops produced in a number of countries and regions of the tropics, including East Africa especially Tanzania ever since it won its independence. The cashew nuts sector is one among the main contributors in the exports basket for Tanzania. The crop stands at third position after tobacco and coffee in foreign exchange earnings from year 2009 to 2011 (CBT, 2012). It contributed 18% of Tanzania's merchandise export earnings in 2012 (PASS, 2013). Cashew is the main cash crop and the leading source of income for over 300,000 households in Southern and Eastern Tanzania. It is estimated that over 80% of the crop comes from Mtwara, Lindi and Ruvuma (Tunduru district) regions (NARI, 2012). The area under cashew has been estimated to be about 400,000 hectares in mono or mixed crop production systems.

Cashew is a highly nutritious and concentrated form of food, providing a substantial amount of energy. The nut kernel has a pleasant taste and can be eaten raw, fried and sometimes salted or sweetened with sugar (FAO, 1998). In Tanzania, the nut is being considered as the most valuable of the cashew tree even though apples are being consumed as fruits (Masawe, 2006). As a fruit, cashew is used to make juice, jam, sweets and gin as well as animal feed.

Despite its usefulness in Tanzania, research records on cashew production in the country indicate low yield as a result of poor yield potential and aging of some genotypes. For instance, it is estimated that more than 80% of the total cashew trees available in Tanzania are the halfsib progenies of the original introductions or their sibs planted in the early 1950s. Owing to this old age, the trees have lost their yield potential which contributed to the decline in nut yield from 145,000 tons in 1973/74 season to 16,000 tons in 1989/90 season (Kasuga, 2010). Adoption of improved cashew planting materials by cashew farmers in more recent years has led to increases in its production from 16,000 tons in 1989/90 season to 200,000 tons in 2014/15 season (NARI, 2014).

Growing of improved cashew genotypes has resulted in an increase of Tanzanian cashew nut yield. However, there is low genetic variation for selection, and the process of hybridization is expensive and takes long time. Introduction of foreign germplasm for hybridization with local genotypes can improve cashew genetic base and therefore offering possibility of selecting high yielding genotypes with desirable characteristics. Cashew hybrids have shown to perform better than their parents and that is why hybridization remains to be the main drive in cashew breeding (NARI, 2014).

Evaluation of hybrids produced in three years (1991, 1994 and 1995) was carried out at Naliendele from 1991 to 2003, from which 32 elite hybrids were selected for further evaluation in advanced trial. The number of outperforming hybrids selected from each trial was 12 (1991), 6 (1994) and 14 (1995). Selection of these hybrids was based on individual tree observations. Since performance of these hybrids was based on data from one tree in a single site (Naliendele Mtwara, 120m above sea level), it was important to test them in contrasting environments to find out if their performance was due to favourable environment or genetic traits. Experiments for evaluation of the hybrids were therefore set at Nachingwea, Lindi (465m above sea level) and Chambezi, Bagamoyo (33m above sea level) in 2005. Cashew trials require large areas (6-10ha) depending on number of entries and replications. The availability of government land was possible only at those two agro-ecological sites.

1.2 Problem Statement and Justification

Cashew is a commercial crop of great importance as it saves as an export commodity and a source of income. In both tropical and sub-tropic countries, cashew plays a key role as a food security and income generating crop (Masawe, 2009). Despite its economic implications, cashew nut production in Tanzania is still very low. The crop has been adversely affected by lack of high performance planting materials, poor management and pests and diseases. Low productivity (0-5kg/tree/year) has been reported in several farmers' fields in Southern and Eastern Tanzania because majority of cashew trees are unimproved and are not well attended too (Masawe, 2006). Most of the local cashew trees in farmers' fields today are progenies of inferior genotypes. Majority of these trees are low yielding with poor nut quality and are susceptible to diseases (NARI, 2012). Developing and identifying high yielding cashew hybrids adaptable to different agro ecological conditions is a way forward towards solving the problem of lack of unimproved varieties. Preliminary studies conducted at Naliendele have shown that hybrids perform better than their parents. However, no study has been undertaken to assess the influence of genotype and environment on the cashew hybrids outside Naliendele. Therefore, this study aimed at identifying high yielding cashew hybrids adaptable to different agro ecological conditions, with prospects of being incorporated into breeding programmes and seed distribution systems in the country.

1.3 Objectives

1.3.1 Overall objective

To establish a recommendation domain for cashew hybrids developed for Southern and Eastern Tanzania

1.3.2 Specific objectives

(i) To evaluate G x E interaction on yield and yield components of developed cashew hybrids in different agro ecological conditions;

(ii) To determine kernel and apple nutritional contents of the hybrids; and

(iii) To determine stability for yield and yield components of the cashew hybrids across locations

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Cashew

Cashew originated in Latin America, specifically Northeastern Brazil (Ohler, 1979). Portuguese explorers introduced it to tropical Asia and Africa from where it spread to other parts of the world. Although Portuguese introduced cashew in East Africa, it was not planted widely in Tanzania until after World War II (Northwood and Kayumbo, 1970) when 7,000 tons of raw nuts were exported to India. Since cashew was not brought to East Africa for the purpose of cultivation, it might have come from unselected seeds representing possibly a narrow genetic base. In Tanzania, (by then Tanganyika), the first germplasm was introduced at Nachingwea (Lindi region) in the 1950s (Kasuga, 2003). Extensive planting of cashew trees took place in 1960s with a marked decline in planting in mid 1970s. However, new plantings started in early 1990s (Kasuga, 2010). As of 2005 about 3 million households in Africa were involved in cashew nut production with an average of 3 hectares cashew trees (Aliyu, 2006).

At present, cashew is produced in 32 countries of the world with sufficient warm and humid climate. The main producers are Brazil, India, Vietnam, Cote d'Ivore, Tanzania, Nigeria, Republic of Benin, Ghana, Guinea, Mozambique, Sri Lanka, and Philippines (Adeigbe *et al.,* 2015). Since most cashew trees start bearing fruits in the third or fourth year, are likely to reach mature yield by the seventh year if conditions remain favourable. The average yield of cashew nuts (unshelled) of a mature tree is in the range of 7-11 kg per annum (FAO, 2004).

2.2 Trend in Cashew Production

Tanzania has a good climate for cashew nut production, especially in the southern coastal region bordering Mozambique. Cashew is grown mainly along the coastal area in Tanzania. However, due to 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 Iringa, Mbeya, Singida, Dodoma, Morogoro, Mbarali, Mbinga and Songea) have started planting cashew trees (Masawe, 2006). Tanzania ranked 8th in production worldwide in 2010, 2011 and 2013 and 7th in 2012 with Vietnam maintaining the first position in all those years (Table 1).

Table 1: Leading cashew producers (tons) worldwide

Country	2010	2011	2012	Country	2013
India	613 000	647 600	680 000	India	753 000
Cote d'Ivore	380 000	452 656	450 000	Cote d'Ivore	450 000
Vietnam	1 242 000	1 272 000	1 190 900	Vietnam	1 110 800
Brazil	104 342	230 785	80 630	Philippines	146 289
Guinea Bissau	91 100	128 687	130 000	Guinea Bissau	138 195
Tanzania	80 000	75 000	122 274	Tanzania	127 947
Nigeria	682 524	813 023	836 500	Nigeria	950 000
Benin	69 700	70 000	170 000	Benin	180 000
Mozambique	67 200	72 263	64 731	Burkina Faso	115 000
Indonesia	145 082	122 100	117 400	Indonesia	117 400

Adapted from Adeigbe *et al.,* 2015 and FAOSTAT, 2015

2.3 Production Constraints

The most serious constraints in the cashew industry in Tanzania is damage by diseases and insect pests. Diseases of economic importance include Powdery Mildew and Leaf and Nut Blight. On the other hand *Helopeltis anacardii* and *Pseudotheraptus wayii* are insect pests of economic importance (Kasuga, 2010). Also, majority of Tanzania cashew farmers are resources poor and cannot afford inputs and services that are crucial for increasing production and quality of nuts. Another production constraint includes low yielding varieties. A significant proportion (up to 30%) of cashew trees in Tanzania are low yielding, producing less than 3kg of cashew nuts per year in the absence of pests and diseases and other agronomic constraints. The situation worsens when pests occur (Kasuga, 2010).

Most of the cashew trees in the country, particularly from the potential growing areas, are very old and unimproved. While there are some young trees that are producing, most of them are still from the same unimproved old varieties. Farmers are therefore faced with the dilemma of low productivity and disease susceptible varieties (ECI Africa, 2003). How to improve productivity is therefore an important challenge that confronts the Tanzanian cashew industry. Identification or developing planting materials that are acceptable in different agro-ecological conditions and markets could be a possible solution. No wonder, therefore, that development of cashew hybrids in Tanzania is currently the focus of cashew breeding activities. Hybridization, nevertheless, is labour intensive and time consuming (Masawe, 2009). The whole process from hand pollination to harvesting takes about three months. Hybrid seeds usually require field evaluation period of not less than five years before mass selection is carried out. The selected elite hybrids need to undergo field evaluation in replicated trials to establish whether the observed performance was genetic or environmental (Masawe, 2009).

2.4 Uses of Cashew

The cashew nut is a popular dessert nut, eaten out of hand, with other mixed nuts and used in baking and confections. It is high in protein, oil and vitamins such as thiamin, with 47% fat, 21% protein and 22% carbohydrate (Ohler, 1979). The nut can also be made into cashew butter and nut milk. The cashew apple is a pseudofruit, the swollen stalk of the true fruit. There are places where people do consume the apple and throw the nut due to its toxicity. The apples are red or yellow in colour, fibrous but juicy, sweet, punget and high in vitamin A and C. Per 100 g of fresh fruit the cashew apple has more vitamin C than mangoes, oranges and guavas (Davis, 1999). However, only a fraction of cashew apples are used, they are quite perishable and can be used only locally unless preserved. Those not eaten fresh can be preserved in syrup, candied, sun-dried, stewed and made into juices, chutneys, jams, pickles and vinegar. Within 24 hours after falling from the tree apples rot.

Alcohol is another use of cashew apple, the squeezed fruit juice ferments quickly without the need for people to do anything making a strong alcoholic drink (Davis, 1999). The cashew nut shell liquid (CNSL) is used in brake linings in cars simply because it absorbs heat very efficiently. Apart from brake lining, CNSL is also used in waterproofing and in paints; treating of scurvy, warts, ringworms and in tattooing (Ohler, 1979). Other parts of the tree are used medicinally in curing of sore throats, chronic dysentery and diarrhea; leaves can be crushed for a poultice for skin ailments, bark chewed for sore gums and toothache (Davis, 1999).

2.5 Nutritional Quality of Cashew

Cashew is a highly nutritious and concentrated form of food. The cashew nut kernel has a pleasant taste and flavor and can be eaten raw, fried and sometimes salted or sweetened with sugar (FAO, 1998). The kernel is considered to be of high nutritive quality; and growing conditions or the variety of cashew may have an influence on kernel composition. The overall composition of the kernel is protein 21%, fat 47% and carbohydrates 22% (Ohler, 1979). The kernel is also very rich in vitamins and minerals (Table 2).

Table 2: Nutritional contents of cashew nut (Nutrition value per 100 g)

Principle	Nutrient value	Percentage of RDA
Energy	553 Kcal	28%
Carbohydrates	30.19 g	23%
Protein	18.22 g	32.50%
Total Fat	43.85 g	146%
Cholesterol	0 mg	0%
Dietary Fiber	3.3 g	8.50%
Vitamins		
Folates	25 µg	6%
Niacin	1.062 mg	6.50%
Pantothenic acid	0.864 mg	17%
Pyridoxine	0.417 mg	32%
Riboflavin	0.058 mg	4.50%
Thiamin	0.423 mg	35%
Vitamin A	0 IU	0%
Vitamin C	0.5 mg	1%
Vitamin E	5.31 mg	35%
Vitamin K	4.1 µg	3%
Electrolytes		
Sodium	12 mg	1%
Potassium	660 mg	14%
Minerals		
Calcium	37 mg	4%
Copper	2.195 mg	244%
Iron	6.68 mg	83.50%
Magnesium	292 mg	73%
Manganese	1.655 mg	72%
Phosphorus	593 mg	85%
Selenium	19.9 µg	36%
Zinc	5.78 mg	52.50%

Source: USDA National Nutrient data base in Hai (2013).

Cashew apple juice is reported to contain five times as much vitamin C as citrus juice (Azam-Ali and Judge, 2001) and ten times as pineapple juice (Ohler, 1979).

2.6 Botanical Descriptions

The cashew tree (*Anacardium occidentale* L.) belongs to the genus *Anacardium*, a member of the family *Anacardiaceae* which comprises about 60 genera and 400 species of trees and shrubs with resinous bark, growing most abundantly in the tropics in both eastern and western hemispheres (Ohler, 1979). It is an evergreen perennial, when growing under favourable conditions and unharmed by pests, the stem is erect and the canopy symmetrical, mostly umbrella shaped. The tree may grow up to a height of 15metres. A healthy tree not suffering from any deficiency, insect attack, disease or other unfavorable conditions, will have a dense foliage that provides a heavy shade even during dry season and almost totally suppresses weed growth. Shoot growth may occur throughout the year especially when rainfall is well distributed. Leaves are leathery, glabrous and thick oblong to obovate and rounded to emarginated at the apex, 10 to 20cm long and 5 to 10cm wide. The petioles are about 0.5 to 1cm long. The leaves are simple, entire and pinnately veined, each leaf having about 20 pairs of prominent veins (Ohler, 1979). They are alternatively arranged on the twig. Cashew has an extensive root system and deep taproot and grows well even in sandy soils with low fertility (Davis, 1999).

Growing conditions and probably genetic factors influence the age at which the cashew tree starts flowering. Although trees growing under favorable conditions may produce their first crop worth harvesting at the age of 3 years, the production of flowers and a few fruits usually takes place in the second year of growth (Ohler, 1979). Masawe (2006) reported that trees flowering at the age of 6 months after transplanting. Trees growing under similar conditions may show differences in time of first flowering as well as in earlier or later flowering within the same season, and this can be genetically determined. Cashew flowering is not affected by day length; trees normally flower at the end of rainy season when new shoots emerge. The flowers develop at the end of the shoots. In areas where there are two dry seasons the trees usually flower twice in a year (Davis, 1999). There are three types of cashew trees as far as flowering is concerned; early middle and late flowering. Cashew flower types are male, abnormal and hermaphrodite (Masawe and Kapinga, 2010). Male flowers have one large stamen (an anther and a filament) and several small stamens. Abnormal flowers are like male flower but they do not have a large stamen. Hermaphrodite flowers have both large and small stamens and in addition they have the female parts (stigma and style). In most cases, the first flowers to open are male and abnormal flowers followed by hermaphrodite flowers (Masawe *et al*., 1996).

Cashew hybridization involves selection of parents, care of the field, care of the parental trees, preparation of pollination bags and hand pollinators. Parents to be used in hybridization need to be selected for nut quality aspects with yield potential as the centre of focus. The panicles to be used in the pollination program should be healthy. Panicles of both male and female parents should be bagged and labelled before flowers begin to open. If few flowers on the panicle have already opened they should be carefully detached using watchmaker's forceps. Each bagged panicle on the female parent tree should be opened daily and all male flowers removed leaving only hermaphrodite flowers. The male flowers should be wholly detached from the cashew tree using fine sterilized watchmaker's forceps and kept in covered petri dishes ready for use.

Each bag on the female parent should be opened, the anther of the male flower should be touched on the stigmas of several flowers in the bag using sterilized watchmaker's forceps. Pollination bags should be resealed using office pins or table clips. The exercise should be repeated daily until there are no more flowers to pollinate in that bagged panicle or there are already more than six successful set fruits (Masawe and Kapinga, 2010). Successful pollination is indicated by the swollen ovary of the female flower.

2.7 Yield Components

One of the primary objectives of cashew breeders is to increase the nut yield. Generally, yield represents the final character resulting from many developmental and biochemical processes which occur between germination and maturity (Aliyu, 2006). Before yield improvements can be realized, the breeder needs to identify the causes of variability in nut yield in any given environment. Crop yield is the product of the individual yield components (morphological characteristics) operating in the crop species in question. Knowledge of the association between traits being improved, e.g. yield and other traits in the population is desirable to a plant breeder. This will enable him to know how the selection pressure exerted by him on one trait will cause changes in other traits. Furthermore, the direction and magnitude of such changes could be made manifest.

Various scholars have undertaken study on cashew yield and yield components such as Aliyu (2006) who had a study on ten cashew traits associated with yield (nut weight, number of nut per panicle, number of nut per tree, nut yield in kg per tree, weight of whole fruit, number of hermaphrodite flower per panicle, pollen grain fertility, days to flower anthesis, tree canopy spread and leaf size). The study showed that, nuts per panicle, number of nuts per tree and number of hermaphrodite flowers per panicle were positively correlated with nut yield and could be used as primary components for improving yield. Kapinga (2009) also studied several traits associated with yield which were nut picking duration, yield per day, nut weight, kernel weight, percentage kernel out turn, nut length and nut thickness. From the study, yield per day and percentage out turn appeared to be positively correlated with yield. Traits associated with yield may be used either as indirect selection criteria or in a selection index for higher yield.

2.8 Yield Potential

This is the yield obtained when an adapted cultivar is grown with the minimal possible stress that can be achieved with best management practices. Although there is some imprecision in the specification of minimal possible stress and best management practices, crop simulation models can provide reasonable estimates of functional yield potential in a given environment based on the physiological relationship that govern plant growth and development (Cassman, 1999).

In Tanzania, cashew has the yield potential of 1ton per hectare (MAFC, 2014), the absolute capacity of the crop to produce economic yield under optimum production conditions.

2.9 Genotype x Environment Interaction

Baker (1988) defined G x E interaction as the failure of genotypes to achieve the same relative performance in different environments. However, in most cases, breeders look for a variety that has good mean performance over a wide array of environments and years and the concept of stability is overlooked. Such approach is reasonable if there is no G x E interaction, but in most cases there is interaction. Gene expression is subject to modification by environment; therefore, genotypic expression of the phenotypic is environment dependent (Kang, 1998).

The performance of particular cultivar is the result of its genetic constitution and the environment in which it has been grown. In practice it is quite possible the same cultivar may not exhibit the same phenotypic performance under different environments. A genotype performing similarly in all environments does not respond to improved growing condition with increased yield, thus this type of stability is not considered desirable (Bathia, 2007). In the absence of G x E interaction, a superior genotype in one environment may be regarded as the superior genotype in all, whereas the presence of the G x E interaction confirms particular genotypes being superior in particular environments. When G x E interaction occurs, factors present in the environment (temperature, rainfall, etc.), as well as the genetic constitution of an individual (genotype), influence the phenotypic expression of a trait. The impact of an environmental factor on different genotypes may vary implying that the productivity of an animal or plant may also vary from one environment to the next. Breeding plans may focus on the G x E interaction to select the best genotype for a target population of environments (Bondari, 1999). Whenever new varieties are proposed for commercial release, information on genotype and environment interactions and stability, clearly indicating their specific and/or general adaptations, are made available to the user (Goncalves *et al.,* 2003). An understanding of genotype x environment interaction can therefore help to identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation (Yan and Hunt, 2002).

2.10 Stability Parameter

Stable varieties are those ones which perform similarly regardless of the productivity level of the environments (Adebis, 2009). Stability of yield of a cultivar across a range of production environments is very important for variety recommendation. The cultivars must have the genetic potential for superior performance under ideal growing conditions, and must also produce acceptable yields under less favorable environments. Therefore, a stable genotype can be referred to as the one that is capable of utilizing the resources available in high yielding environments and has a mean performance that is above average in all environments (Eberhart and Russell, 1966). There are different methods that are used in determination of stability which include; genotype variance, coefficient of variation, ecovalence, stability variance, regression coefficient and deviations from regression. Ecovalence method is the simplest method, based on the dynamic concept of stability. It was proposed by Wricke (1962), who defines the term ecovalence as the contribution of each genotype in all environments, to the sum of squares of the G x E interaction. If ecovalence is small, agronomic stability is high. Evaluating stability of performance and range of adaptation has become increasingly important for breeding programs, and to identify stable genotypes whose yield performance remains high across a range of environmental conditions is the primary goal of most plant breeders.

2.11 Path Coefficient Analysis

Statistical methods which have been developed to quantify relationships among traits in crop plants are correlation and regression analyses. Correlation analysis quantifies the relationships between any given pair of traits without regards to cause/effect relationship (Aliyu, 2006). Multiple regression analysis could be used to predict the performance of a dependent or resultant variable such as nut yield on the basis of a given set of independent or causal variables. Despite the predictive role played by various multiple regression models, the interrelationships among causal variables cannot be clearly elucidated by multiple regression analysis.

Path coefficient analysis can be used to get over the limitations of the first two techniques (Aliyu, 2006). Correlation studies permit only a measure of relationship between two traits. Path coefficient analysis becomes necessary as it permits separation of direct (independent) and indirect (dependent) effects via other related characters by partitioning the correlation coefficients (Dewey and Lu, 1959). Path coefficient analysis differs from simple correlation in 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). Indeed, the path analysis is more informative and useful in determining the nature and relationships between yield and yield components than simple correlation coefficients.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Sites and Materials

The experiment was conducted during the 2014/2015 cropping season in the Southern (Nachingwea) and Eastern (Chambezi) zones of Tanzania. Nachingwea is located at 10°20'S, 38°46'E, altitude 465m; and Chambezi at 6°31'S, 38°55'E and altitude 33m above sea level.

Twenty nine developed cashew hybrids planted in 2005 (H1, H2, H3, H4, H5, H6, H7, H8, H9, H10, H11, H12, H13, H14, H15, H16, H17, H18, H19, H21, H22, H23, H24, H25, H26, H27, H28, H29 and H30) and a certified variety (AC4) as the control were used in this study. These hybrids were already established in fields of 6 hectares at Nachingwea and Chambezi, sites respectively.

3.2 Methods

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. A plot comprised of four trees planted in a row and spaced 12 m between plants and 12 m between plots.

3.3 Data Collection

Data were collected from the four trees in each plot, mean per each plot was then calculated. Therefore for each parameter observed the mean were calculated before were further subjected to analysis.

3.3.1 Yield

The fallen cashew nuts from every tree were collected daily using collection bags and their weight recorded using weighing balance. Total yield for each hybrid was recorded at the end of the season.

3.3.2 Nut weight

Nut weight was determined by measuring weight of 500gm of sampled nuts randomly selected and then divided by the number of nuts.

3.3.3 Kernel weight

Using the same sample as for nut weight, the nuts were dissected (opened up) longitudinally to take out the kernels and were weighed. The obtained weights were divided by the number of nuts.

3.3.4 Percentage kernel out turn

Percentage kernel out turn, simply refers to what proportion of useful kernels obtained in a given unit of raw nuts. Percentage kernel out turn was determined by measuring the weight of useful kernels and dividing it by nut weight and then multiplying by the 100.

3.3.5 Nuts per tree

Using the nuts collected at each tree for yield determination, they were counted per tree and number recorded.

3.3.6 Nuts per panicle

Each tree with the panicles in the field was visited, panicles representing every side of the tree were randomly selected and the number of nuts counted and recorded.

3.3.7 Leaf and nut blight disease

Blight disease incidence data were collected from the four geographical sides of the test trees using quadrat system. A label was tagged to a central shoot on each of the four sides of the tree. During scoring a 1m² quadrat was placed so that the tagged shoot was at the centre of the quadrat in order to ensure that at least more or less same shoots were assessed throughout the trial season. Total number of shoots enclosed within the quadrat and number of shoots showing blights symptoms were recorded for percent incidence. Overall, blight score per test tree was recorded using 0-6 disease score index, to indicate the levels of blight infection whereby 0 = no diseases at all, 1= 1-10% infected, 2=11-30% infected, 3=31-50% infected, 4=51-60% infected, 5=61-80% infected and 6=81-100% infected. Percentage of infection recorded was for shoot surface scored in which leaves and nuts were inclusive.

3.3.8 Fat content determination

Fat content was determined by Soxhlet Continuous Extraction method. Kernel samples each weighing 50g was milled and a fine powder was separated using a 1mm sieve. Samples (3g each) of the powder were put into a thimble. The thimble containing the weighed sample of kernel powder was put in weighed soxtec cup, which was oven dried before for 2 hours and cooled in desiccators for half an hour. Forty mm of solvent (petroleum ether) was added into the cups. The cups with the content was then placed in the soxtec machine and boiled for 1hour at 107^{o}C. The cooling unit of soxtec machine was set at about 14^{o}C to cool the solvent. Thereafter the remaining solutions in the cup was placed in oven set at 100^{o}C for half an hour to evaporate unwanted materials such as the traces of solvent and water. It was then removed and cooled in dessicators for half an hour; 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. The percentage fat content in the sample was calculated using the formula:

% Fat content = (weight of fat with cup/weight of cup with kernel powder) x 100

3.3.9 Protein content determination

Protein content was determined using Kjeldalh method (1883). 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 10:1:10, respectively then introduced into the digestion cup containing the kernel sample. This was followed by 6ml conc. sulphuric acid. The samples was then placed in the digestion chamber and heated for one hour, thereafter the sample was allowed to cool. Then fractional distillation was carried out to separate ammonia from the digested content. The ammonia was collected in a conical flask containing 25ml of boric acid. The boric acid used to trap up ammonia gas to form ammonium borate. The ammonium solution (ammonium borate) was titrated against hydrochloric acid to obtain the actual content of ammonia released. Amount of nitrogen (N) was determined from the ammonia, which was then used to calculate the actual protein content in the sample using the formulae:

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

Whereby:

N = nitrogen

Conc. HCl = Concentrated hydrochloric acid (M)

Crude Protein (CP) is then calculated as:

CP = %N x factor;

Factor = 6.25

3.3.10 Mineral determination

Sample from kernel powder (each 5g) was put in crucibles and burned in blast furnace at 500^{o}C for 3 hours to destroy organic matter. After burning, ashes was allowed to cool. Then each sample was dissolved in 10ml 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 then transferred into 100ml volumetric flask. Distilled water was added into the filtrate to make up 100ml volume of the filtrate ready for mineral determination.

3.3.11 Calcium, magnesium, potassium and sodium

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

3.3.12 Iron, zinc and copper

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

3.3.13 Vitamin C determination

Fruits from each plot in each replication to represent a single hybrid was collected in each site, sorted, washed with clean water, macerated and the juice sieved (cheese cloth) using sterile equipment and thereafter frozen at -20°C until analysed. Vitamin C was determined by iodine titration (AOAC, 2000). To 25 mL of juice in a 150 mL beaker, 35 mL starch-sulphuric acid solution was added. The resulting solution was titrated with standardised 0.1 M iodine solution (covered from light), while stirring until the first stable blue colour appeared. For the blank, juice was replaced with distilled water. Ascorbic acid (mg/100 mL) was calculated from the formula:

Ascorbic acid (mg/100mL) = (Net mL titrant/mL sample) x 880.6

Where:

Net mL titrant = mL titrant for sample – mL titrant for blank

3.4 Data Analysis

Specific objective (i) To evaluate G x E interaction on yield and yield components of developed cashew hybrids in two different agro ecological conditions.

3.4.1 Analysis of variance

Data were subjected to ANOVA using Genstat statistical package 16th edition so as to determine the performance of genotypes on different sites. The statistical model was as follows; $Yijk = \mu + Gi + Ej + GEij + Bjk + \varepsilon ijk$

Where by μ is the mean, *Gi* is the effect of the *ith* genotype, *Ej* is the effect of the *jth* environment, *Geij* is the interaction of the *ith* genotype with the *jth* environment, *Bjk* is the effect of the *kth* replication in the *jth* environment, and *εijk* is the random error. Tukey's test was used for mean separation.

3.4.2 Path coefficient analysis

Path coefficient analysis was carried out as described by Dewey and Lu (1959). The relationships among yield and yield components computed at each location and across locations on combined analysis. The relationship between correlation coefficients and path coefficients was established using the path coefficient diagram (as illustrated in Fig. 1) and simultaneous equations arranged in matrix form. The method involves solving of unknowns (path coefficients) from a series of simultaneous equations.

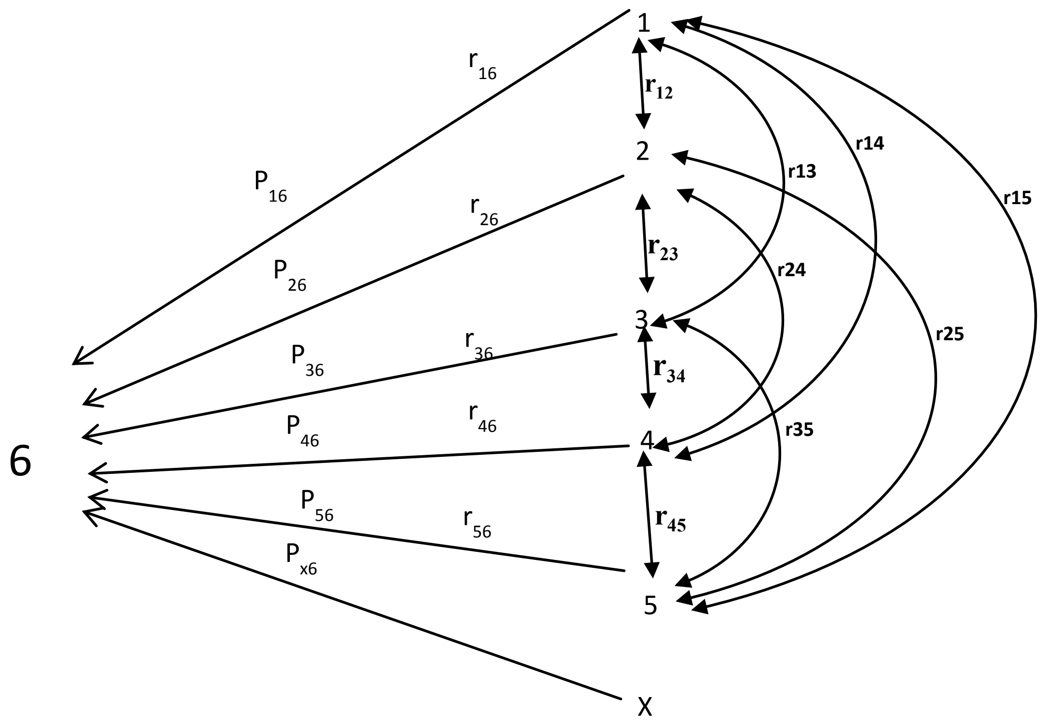

Figure 1: Path diagram showing direct and indirect effects on yield and yield components

Key: (1) = Nut weight; (2) = Nuts per tree; (3) = Kernel weight; (4) = Percentage out turn; (5) = Nuts per panicle; (6) =Yield and (X) = Residual effect.

In the path diagram, the double-arrowed lines indicate mutual associations as measured by correlation coefficients, r, and the single arrowed lines represent direct influence as measured by path coefficients P.

Simultaneous Equations used in the computation of rP's

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

$$r_{26} = r_{12}P_{16} + P_{26} + r_{23}P_{36} + r_{24}P_{46} + r_{25}P_{56}$$

$$r_{36} = r_{13}P_{16} + r_{23}P_{26} + P_{36} + r_{34}P_{46} + r_{35}P_{56}$$

$$r_{46} = r_{14}P_{16} + r_{24}P_{26} + r_{34}P_{36} + P_{46} + r_{45}P_{56}$$

$$r_{56} = r_{15}P_{16} + r_{25}P_{26} + r_{35}P_{36} + r_{45}P_{46} + P_{56}$$

Computation of residual factor (Px6) was based on the following equation;

$$1 = P^2X_6+P^2_{16}+P^2_{26}{}^+P^2_{36}+P^2_{46}+P^2_{56}+2P_{16}r_{12}P_{26}+2P_{16}r_{13}P_{36}+2P_{16}r_{14}P_{46}+ 2P_{16}r_{15}P_{56}+2P_{26}r_{23}P_{36}+2P_{26}r_{24}P_{46}+2P_{26}r_{25}P_{56}+2P_{36}r_{34}P_{46}+2P_{36}r_{35}P_{56}+ 2P_{46}r_{45}P_{56}$$

The indirect effects of a variable on yield (rP's) are the product of the correlation coefficient (r) and the direct effect (P).

Explanations basing on the path model:

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

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 residue effect in the path analysis model; i and j = (1,2,3, …..8)

Specific objective (ii) To determine kernel and apple nutritional contents of selected cashew hybrids

Data were subjected to ANOVA using Genstat statistical package (16th edition), the same statistical model as for objective 1 was used.

Specific objective (iii) To determine stability for yield and yield components of cashew hybrids across locations

Data cleaning for the collected data as for specific objective 1 were undertaken, then subjected to statistical analysis with Agrobase program using Wi-ecovalence.

Stability analysis was performed using ecovalence (Wi): Ecovalence is defined as the contribution of each genotype (cultivated in different environments) to the total genotype x environment interaction. Genotypes with low ecovalence values are considered as stable.

Wricke's ecovalence (*Wi)* was calculated using the following formula:

$Wi=Sj\ (Yij - Yi.-Y.j + Y..)2$,

Where *Wi* = ecovalence value of genotype *i,*

Sj= sum of *j* values in each genotype environment,

Yij = mean of genotype *i* in environment *j*, *Yi* = mean of genotype *i* in all environments,

Y.j= environment average *j*, and

Y..= overall average of all environments.

CHAPTER FOUR

4.0 RESULTS

4.1 General Profile of the Study Area

Results of soil characterization and weather observation for the trial sites are presented briefly in this chapter and the data attached in Appendices 1 and 2. Soil characteristics varied across locations (environments). Nachingwea had clay soil with pH 5.5 whereas Chambezi had sandy loam with pH 6.6 (Appendix 1). The weather conditions during the cropping season at Nachingwea and Chambezi are presented in Appendix 2. At Chambezi, rainfall distribution was throughout the growing season and was relatively high compared to the other site. At Nachingwea, maximum monthly rainfall was 275.9 mm in February 2014 while the minimum monthly rainfall was 0 mm recorded in June, July, August and September 2014. The total annual rainfall during the whole period of growing season was 1043.3 mm. Mean maximum temperature was 27.76^{o}C in November 2014 while minimum temperature was 22.78^{o}C in July 2014. At Chambezi site, the temperature varied between 25.73-29.33^{o}C. The maximum rainfall was 405 mm recorded in May while minimum was 0.2 mm in January 2014. The total annual rainfall during the entire growing period was 1730.2 mm.

4.2 ANOVA for the Studied Agronomic Variables

Table 3 provides analysis of variance summary for the studied variables at both locations and the combined analysis. The results showed significant differences among the hybrids for all characters studied at all locations. Locations on the other hand differed significantly for all the studied variables. Hybrids x locations interaction also displayed significant effects for all variables.

Table 3: Analysis of variance for studied cashew yield, yield components and blight disease at Nachingwea, Chambezi and in combined analysis

Source of variation	DF	Mean square ANOVA values						
		YLD	NTWT	NTPCL	NTPT	KNWT	%OT	CLNBD
Nachingwea								
REP	2	15.36	1.05*	0.23	165799	0.03	3.07	1833.3***
HYBRID	29	23.95***	2.88***	2.63***	1049635***	0.20***	5.93***	330.4***
Error	58	8.32	0.32	0.71	171779	0.02	1.47	131.9
Total	89							
Chambezi								
REP	2	11.36	0.03	4.44**	52311	0.04	4.58	1047.1*
HYBRID	29	53.64***	2.16***	6.02***	1135778***	0.16***	6.65**	756.1***
Error	58	18.70	0.51	0.76	337450	0.04	2.98	222.9
Total	89							
Combined analysis								
REP	2	26.29	0.44	1.33	198802	0.03	6.30	2819.1***
HYBRID	29	35.77***	3.53***	6.51***	1197035***	0.25***	8.14***	569.1***
LOCATION	1	1053.49***	16.26***	2.93*	26623060***	1.99***	14.45*	25353.2***
LOCATION*HYBRID	29	41.83***	1.51***	2.14***	988378***	0.11***	4.44**	517.4***
Error	118	13.29	0.42	0.78	250626	0.03	2.21	175.4
Total	179							

Key: DF = Degrees of freedom, YLD = Yield (kg/tree), NTWT = Nut weight (g), NTPCL =Nuts per panicle, NTPT = Nuts per tree, KNWT = Kernel weight (g), %OT = Percentage out turn, CLNBD = Cashew leaf and nut blight disease. * Significant at P ≤ 0.05, ** significant at P ≤ 0.01, *** significant at P ≤ 0.001

4.3 Effect of Hybrids on Yield and Yield Components of Cashew

Results on effects of the hybrids are presented in Tables 4 and 5 for individual locations as well as combined data in Table 6. Genotypic performance for each variable parameter is as follows:

4.3.1 Yield

At Nachingwea, the yield ranged from 13.91kg/tree to 24.11kg/tree (Table 4). H4, H30, H5 and H29 had the highest yields while H14 recorded the lowest yield which was significantly different (P≤0.05) from the four highest yielders. Many hybrids were statistically similar in yield. Although the control AC4 ranked 18th it was not statistically different from H4 which ranked first. From the data, all hybrids with yield above 15kg/tree were statistically the same as H4, the highest yielder. On the other hand, all hybrids yielding less than 22.47kg/tree from the data were not statistically better than the lowest yielder (P≤0.05).

At Chambezi, yields were lower compared to Nachingwea and ranged from 9.48kg/tree to 26.92kg/tree (Table 5). The highest yield was exhibited by H26 which differed significantly (P≤0.05) from the control AC4 while the lowest was exhibited by H25. The highest yielding hybrid H26 was statistically similar to other 16 hybrids at the site; all those with yield above 12.91kg/tree. The control was having yield of about 11.47kg/tree which ranked 21st.

Table 4: Mean performance for yield, yield components and blight disease of cashew hybrids at Nachingwea

Hybrid	YLD(kg/tree)	NTWT(g)	NTPT	NTPCL	KNWT(g)	%OT	CLNBD (%)
H1	16.56^{ab}(25)	8.52^{abcd}(9)	1977^{cdef}(26)	5.33^{abc}(6)	2.26^{bcde}(15)	26.57^{bcd}(26)	18.06^{abc}(26)
H2	21.16^{ab}(10)	5.76^{g}(30)	3746^{ab}(2)	4.33^{abc}(15)	1.73^{fg}(29)	30.15^{abc}(3)	33.34^{abc}(10)
H3	16.37^{ab}(26)	7.59^{cdef}(22)	2136^{cdef}(22)	4.66^{abc}(13)	2.24^{bcde}(17)	29.50^{abcd}(7)	37.73^{abc}(4)
H4	24.11^{a}(1)	7.72^{cde}(20)	3041^{abcde}(6)	3.66^{bc}(27)	2.22^{cde}(18)	28.75^{abcd}(12)	27.78^{abc}(15)
H5	24^{a}(3)	8.07^{abcde}(13)	3185^{abcd}(4)	4.0^{abc}(24)	2.28^{bcde}(13)	28.43^{abcd}(15)	34.03^{abc}(6)
H6	21.10^{ab}(11)	7.92^{bcde}(16)	2664^{bcdef}(15)	3.33^{bc}(28)	2.21^{cde}(19)	27.93^{abcd}(19)	22.45^{abc}(18)
H7	21.17^{ab}(9)	7.47^{defg}(23)	2837^{abcdef}(8)	3.0^{c}(30)	2.26^{bcde}(14)	30.33^{ab}(2)	22.22^{abc}(19)
H8	19.86^{ab}(17)	8.52^{abcd}(8)	2363^{cdef}(18)	4.0^{abc}(25)	2.31^{bcde}(11)	27.22^{bcd}(22)	34.03^{abc}(7)
H9	16.67^{ab}(23)	8.90^{abcd}(4)	1887^{def}(28)	4.0^{abc}(26)	2.43^{abc}(7)	27.35^{bcd}(21)	31.25^{abc}(11)
H10	16.99^{ab}(22)	7.87^{bcde}(18)	2176^{cdef}(21)	4.0^{abc}(17)	2.06^{cdefg}(24)	26.31^{cd}(27)	33.80^{abc}(8)
H11	15.68^{ab}(29)	8.79^{abcd}(6)	1750^{ef}(29)	4.0^{abc}(18)	2.51^{abc}(3)	26.88^{bcd}(25)	29.86^{abc}(12)
H12	15.74^{ab}(28)	8.04^{abcde}(15)	1978^{cdef}(25)	5.33^{abc}(7)	2.17^{cdef}(21)	27.15^{bcd}(23)	33.80^{abc}(9)
H13	18.24^{ab}(20)	8.34^{abcde}(11)	2188^{cdef}(20)	4.66^{abc}(10)	2.18^{cdef}(20)	26.17^{d}(28)	44.84^{ab}(3)
H14	13.91^{b}(30)	9.61^{ab}(2)	1516^{f}(30)	6.66^{a}(1)	2.45^{abc}(5)	25.83^{d}(30)	51.39^{a}(1)
H15	21.72^{ab}(7)	7.83^{bcde}(19)	2818^{bcdef}(9)	3.0^{c}(29)	2.25^{bcde}(16)	28.82^{abcd}(11)	19.44^{abc}(23)
H16	20.22^{ab}(15)	8.41^{abcde}(10)	2403^{cdef}(17)	4.0^{abc}(19)	2.48^{abc}(4)	29.64^{abcd}(5)	25.69^{abc}(17)
H17	16.63^{ab}(24)	8.55^{abcd}(7)	1960^{cdef}(27)	5.66^{abc}(4)	2.31^{bcde}(12)	27.04^{bcd}(24)	21.29^{abc}(21)
H18	20.93^{ab}(12)	7.39^{defg}(24)	2879^{abcde}(7)	4.0^{abc}(20)	2.09^{cdefg}(23)	28.39^{abcd}(16)	28.24^{abc}(14)
H19	22.46^{ab}(5)	9.34^{abc}(3)	2274^{cdef}(19)	4.33^{abc}(14)	2.68^{ab}(2)	28.74^{abcd}(13)	19.21^{abc}(24)
AC4	19.26^{ab}(18)	9.81^{a}(1)	1990^{cdef}(24)	5.0^{abc}(8)	2.86^{a}(1)	28.64^{abcd}(14)	34.72^{abc}(5)
H21	17.49^{ab}(21)	6.63^{efg}(27)	2724^{bcdef}(11)	4.0^{abc}(21)	1.86^{efg}(28)	28.2^{abcd}(17)	49.54^{a}(2)
H22	20.02^{ab}(16)	7.89^{bcde}(17)	2586^{bcdef}(16)	4.66^{abc}(11)	2.05^{cdefg}(25)	26.05^{d}(29)	15.28^{abc}(27)
H23	19.12^{ab}(19)	7.35^{defg}(25)	2711^{bcdef}(12)	6.66^{a}(2)	2.16^{cdefg}(22)	29.49^{abcd}(8)	27.08^{abc}(16)
H24	20.76^{ab}(13)	7.71^{cde}(21)	2695^{bcdef}(14)	4.0^{abc}(22)	2.41^{abc}(8)	31.30^{a}(1)	6.94^{c}(30)
H25	21.89^{ab}(6)	8.10^{abcde}(12)	2745^{bcdef}(10)	4.33^{abc}(16)	2.39^{bc}(9)	29.60^{abcd}(6)	18.75^{abc}(25)
H26	21.26^{ab}(8)	6.60^{efg}(28)	3223^{abc}(3)	4.66^{abc}(12)	1.91^{defg}(26)	28.95^{abcd}(10)	15.28^{abc}(28)
H27	20.44^{ab}(14)	6.68^{efg}(26)	3162^{abcd}(5)	4.0^{abc}(23)	1.87^{efg}(27)	28.20^{abcd}(18)	11.11^{bc}(29)
H28	16.31^{ab}(27)	8.06^{abcde}(14)	2087^{cdef}(23)	5.0^{abc}(9)	2.36^{bcd}(10)	29.38^{abcd}(9)	28.24^{abc}(13)
H29	23.55^{a}(4)	5.78^{fg}(29)	4155^{a}(1)	5.66^{abc}(5)	1.71^{g}(30)	29.68^{abcd}(4)	21.76^{abc}(20)
H30	24.08^{a}(2)	8.90^{abcd}(5)	2704^{bcdef}(13)	6.0^{ab}(3)	2.44^{abc}(6)	27.66^{abcd}(20)	20.83^{abc}(22)
Mean	19.59	7.94	2552.05	4.53	2.24	28.28	27.27
SE±	2.88	0.56	414.46	0.84	0.14	1.21	11.48
%CV	14.7	7.1	16.2	18.7	6.3	4.3	42.1
P-value	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Tukey's Test.
Key: YLD = Yield (kg/tree), NTWT = Nut weight (g), NTPCL =Nuts per panicle, NTPT = Nuts per tree, KNWT = Kernel weight (g), %OT = Percentage out turn, CLNBD = Cashew leaf and nut blight disease. Numbers in parentheses indicate hybrid ranking

Table 5: Mean performance for yield, yield components and blight disease of cashew hybrids at Chambezi

Hybrid	YLD(kg/tree)	NTWT(g)	NTPT	NTPCL	KNWT(g)	%OT	CLNBD (%)
H1	18.87^{abc}(4)	6.95^{e}(30)	2692^{abc}(3)	4.33^{cdef}(13)	2.05^{e}(30)	29.49^{abc}(12)	60.65^{abc}(9)
H2	10.52^{bc}(27)	8.36^{abcde}(17)	1278^{bc}(23)	3.66^{def}(19)	2.55^{abcde}(11)	30.39^{ab}(4)	77.78^{a}(1)
H3	14.91^{abc}(14)	8.21^{abcde}(19)	1938^{abc}(12)	2.66^{ef}(28)	2.34^{abcde}(21)	28.88^{abc}(18)	61.11^{abc}(8)
H4	11.18^{bc}(23)	9.15^{abcde}(8)	1220^{bc}(25)	3.0^{def}(25)	2.44^{abcde}(16)	27.83^{abc}(24)	57.41^{abc}(10)
H5	18.69^{abc}(5)	7.56^{bcde}(25)	2561^{abc}(4)	3.0^{def}(26)	2.23^{abcde}(23)	29.53^{abc}(11)	15.74^{c}(30)
H6	15.80^{abc}(11)	8.72^{abcde}(16)	1743^{abc}(15)	3.66^{def}(20)	2.43^{abcde}(18)	28.09^{abc}(22)	39.59^{abc}(25)
H7	9.62^{bc}(29)	7.96^{abcde}(23)	1159^{bc}(26)	4.66^{cdef}(12)	2.38^{abcde}(20)	29.99^{abc}(6)	54.86^{abc}(13)
H8	12.91^{bc}(18)	9.57^{abcd}(4)	1328^{bc}(21)	3.0^{def}(27)	2.73^{abcd}(5)	28.40^{abc}(21)	25.0^{bc}(28)
H9	12.48^{bc}(20)	9.35^{abcd}(6)	1346^{bc}(20)	2.66^{ef}(29)	2.56^{abcde}(10)	27.37^{abc}(27)	41.67^{abc}(23)
H10	15.67^{abc}(12)	7.45^{cde}(27)	2157^{abc}(6)	3.33^{def}(21)	2.17^{cde}(26)	29.17^{abc}(14)	68.29^{ab}(6)
H11	23.40^{ab}(2)	7.99^{abcde}(22)	3015^{ab}(2)	2.33^{f}(30)	2.40^{abcde}(19)	30.06^{abc}(5)	51.39^{abc}(14)
H12	12.62^{bc}(19)	7.04^{e}(29)	1800^{abc}(14)	4.66^{cdef}(8)	2.09^{de}(29)	29.71^{abc}(9)	45.83^{abc}(19)
H13	17.04^{abc}(10)	8.04^{abcde}(20)	2125^{abc}(10)	3.33^{def}(22)	2.29^{abcde}(22)	28.50^{abc}(20)	50.69^{abc}(16)
H14	14.27^{abc}(15)	9.03^{abcde}(9)	1441^{bc}(18)	5.0^{bcdef}(6)	2.20^{bcde}(24)	24.50^{c}(30)	47.91^{abc}(18)
H15	19.25^{abc}(3)	8.99^{abcde}(12)	2152^{abc}(8)	4.66^{cdef}(9)	2.46^{abcde}(13)	27.37^{abc}(28)	69.44^{ab}(4)
H16	13.19^{abc}(16)	9.01^{abcde}(10)	1447^{bc}(17)	3.33^{def}(23)	2.46^{abcde}(12)	27.39^{abc}(26)	49.30^{abc}(17)
H17	17.87^{abc}(8)	9.0^{abcde}(11)	2128^{abc}(9)	7.66^{ab}(2)	2.67^{abcde}(6)	29.64^{abc}(10)	36.11^{abc}(26)
H18	10.91^{bc}(25)	7.50^{cde}(26)	1369^{bc}(19)	3.66^{def}(17)	2.17^{cde}(25)	28.99^{abc}(16)	76.85^{a}(2)
H19	11.20^{bc}(22)	9.85^{ab}(2)	1156^{bc}(27)	3.66^{def}(18)	2.83^{ab}(3)	28.71^{abc}(19)	68.52^{ab}(5)
AC4	11.47^{bc}(21)	9.17^{abcde}(7)	1300^{bc}(22)	5.33^{bcde}(5)	2.66^{abcde}(8)	29.09^{abc}(15)	44.45^{abc}(21)
H21	10.99^{bc}(24)	7.91^{abcde}(24)	1228^{bc}(24)	5.0^{bcdef}(7)	2.16^{cde}(27)	27.47^{abc}(25)	66.67^{ab}(7)
H22	17.98^{abc}(7)	8.77^{abcde}(15)	2154^{abc}(7)	4.33^{cdef}(14)	2.44^{abcde}(17)	27.86^{abc}(23)	31.25^{abc}(27)
H23	13.0^{abc}(17)	8.96^{abcde}(13)	1629^{abc}(16)	6.66^{abc}(3)	2.86^{a}(1)	31.87^{a}(1)	54.86^{abc}(12)
H24	15.41^{abc}(13)	9.70^{abc}(3)	1835^{abc}(13)	3.0^{def}(24)	2.78^{abc}(4)	28.97^{abc}(17)	51.39^{abc}(15)
H25	9.48^{c}(30)	8.35^{abcde}(18)	1143^{c}(28)	5.66^{abcd}(4)	2.56^{abcde}(9)	30.67^{ab}(2)	42.36^{abc}(22)
H26	26.92^{a}(1)	8.01^{abcde}(21)	3414^{a}(1)	4.0^{cdef}(16)	2.44^{abcde}(15)	30.63^{ab}(3)	75.0^{a}(3)
H27	17.36^{abc}(9)	8.87^{abcde}(14)	1982^{abc}(11)	4.66^{cdef}(10)	2.66^{abcde}(7)	29.95^{abc}(7)	45.14^{abc}(20)
H28	10.27^{bc}(28)	9.54^{abcd}(5)	1084^{c}(30)	4.66^{cdef}(11)	2.46^{abcde}(14)	25.88^{bc}(29)	56.94^{abc}(11)
H29	18.65^{abc}(6)	7.28^{de}(28)	2548^{abc}(5)	8.33^{a}(1)	2.16^{cde}(28)	29.73^{abc}(8)	41.67^{abc}(24)
H30	10.60^{bc}(26)	9.87^{a}(1)	1115^{c}(29)	4.33^{cdef}(15)	2.86^{a}(2)	29.20^{abc}(13)	22.22^{bc}(29)
Mean	14.75	8.54	1782.88	4.27	2.45	28.84	51.0
SE±	4.32	0.71	580.90	0.87	0.20	1.72	14.92
%CV	29.3	8.4	32.6	20.5	8.2	6.0	29.3
P-value	0.001	0.001	0.001	0.001	0.001	0.001	0.001

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

Key: YLD = Yield (kg/tree), NTWT = Nut weight (g), NTPCL =Nuts per panicle, NTPT = Nuts per tree, KNWT = Kernel weight (g), %OT = Percentage out turn, CLNBD = Cashew leaf and nut blight disease. Numbers in parentheses indicate hybrid ranking

Table 6: Combined analysis data averages of yield, yield components and blight disease of cashew hybrids grown at Nachingwea and Chambezi

Hybrid	YLD(kg/tree)	NTWT(g)	NTPT	NTPCL	KNWT(g)	%OT	CLNBD (%)
H1	17.72^{ab} (10)	7.73^{cdefgh}(22)	2335^{abc}(9)	4.83^{bcde}(9)	2.16^{defgh}(24)	28.03^{abcd}(21)	39.35^{abcd}(17)
H2	15.84^{b}(21)	7.06^{gh}(29)	2512^{abc}(5)	4.0^{cde}(17)	2.14^{defgh}(25)	30.27^{ab}(2)	55.56^{ab}(2)
H3	15.64^{b} (23)	7.90^{bcdefgh}(19)	2037^{bc}(18)	3.66^{de}(23)	2.29^{bcdefgh}(18)	29.19^{abc}(8)	49.42^{abcd}(6)
H4	17.65^{ab}(11)	8.43^{abcdefg}(11)	2131^{bc}(15)	3.33^{de}(28)	2.33^{bcdefg}(14)	28.29^{abcd}(19)	42.59^{abcd}(11)
H5	21.34^{ab}(2)	7.81^{cdefgh}(20)	2873^{ab}(3)	3.5^{de}(25)	2.25^{cdefgh}(20)	28.98^{abc}(10)	24.89^{cd}(28)
H6	18.45^{ab}(8)	8.32^{abcdefg}(15)	2203^{bc}(11)	3.5^{de}(26)	2.32^{bcdefgh}(17)	28.01^{abcd}(22)	31.02^{abcd}(22)
H7	15.40^{b}(24)	7.72^{cdefgh}(23)	1998^{bc}(19)	3.83^{de}(20)	2.32^{bcdefg}(15)	30.16^{abc}(3)	38.54^{abcd}(18)
H8	16.39^{ab}(17)	9.05^{abcd}(6)	1846^{bc}(25)	3.5^{de}(27)	2.52^{abcd}(5)	27.81^{abcd}(24)	29.51^{abcd}(24)
H9	14.57^{b}(26)	9.13^{abc}(5)	1616^{c}(28)	3.33^{de}(29)	2.49^{abcdef}(7)	27.36^{bcd}(27)	36.46^{abcd}(20)
H10	16.33^{ab}(18)	7.66^{defgh}(24)	2166^{bc}(13)	3.66^{de}(21)	2.12^{fgh}(28)	27.74^{abcd}(25)	51.04^{abc}(4)
H11	19.54^{ab}(5)	8.39^{abcdefg}(13)	2382^{abc}(7)	3.16^{e}(30)	2.45^{abcdef}(11)	28.47^{abc}(15)	40.62^{abcd}(14)
H12	14.18^{b}(28)	7.54^{efgh}(25)	1889^{bc}(24)	5.0^{bcde}(7)	2.13^{efgh}(27)	28.43^{abcd}(17)	39.81^{abcd}(15)
H13	17.64^{ab}(12)	8.19^{abcdefg}(17)	2156^{bc}(14)	4.0^{cde}(15)	2.23^{cdefgh}(22)	27.33^{bcd}(28)	47.77^{abcd}(7)
H14	14.09^{b}(29)	9.32^{ab}(4)	1479^{c}(30)	5.83^{abc}(4)	2.32^{bcdefg}(16)	25.16^{d}(30)	49.65^{abcd}(5)
H15	20.48^{ab}(4)	8.41^{abcdefg}(12)	2485^{abc}(6)	3.83^{de}(18)	2.35^{bcdefg}(13)	28.09^{abcd}(20)	44.44^{abcd}(9)
H16	16.71^{ab}(16)	8.71^{abcdef}(9)	1925^{bc}(22)	3.66^{de}(22)	2.47^{abcdef}(10)	28.51^{abc}(14)	37.50^{abcd}(19)
H17	17.25^{ab}(14)	8.78^{abcde}(8)	2044^{bc}(17)	6.66^{ab}(2)	2.49^{abcdef}(8)	28.34^{abcd}(18)	28.70^{bcd}(26)
H18	15.92^{b}(20)	7.44^{efgh}(26)	2124^{bc}(16)	3.83^{de}(19)	2.13^{defgh}(26)	28.69^{abc}(13)	52.55^{abc}(3)
H19	16.83^{ab}(15)	9.59^{a}(1)	1715^{c}(26)	4.0^{cde}(16)	2.75^{a}(2)	28.72^{abc}(12)	43.87^{abcd}(10)
AC4	15.36^{b}(25)	9.49^{a}(2)	1645^{c}(27)	5.16^{abcd}(5)	2.76^{a}(1)	28.86^{abc}(11)	39.58^{abcd}(16)
H21	14.24^{b}(27)	7.27^{fgh}(28)	1976^{bc}(20)	4.5^{cde}(11)	2.01^{gh}(29)	27.83^{abcd}(23)	58.10^{a}(1)
H22	19.0^{ab}(6)	8.33^{abcdefg}(14)	2370^{abc}(8)	4.5^{cde}(12)	2.24^{cdefgh}(21)	26.95^{cd}(29)	23.27^{cd}(29)
H23	16.06^{ab}(19)	8.16^{abcdefg}(18)	2170^{bc}(12)	6.66^{ab}(3)	2.51^{abcde}(6)	30.68^{a}(1)	40.97^{abcd}(13)
H24	18.08^{ab}(9)	8.71^{abcdef}(10)	2265^{abc}(10)	3.5^{de}(24)	2.59^{abc}(4)	30.13^{abc}(5)	29.17^{abcd}(25)
H25	15.68^{b}(22)	8.22^{abcdefg}(16)	1944^{bc}(21)	5.0^{bcde}(8)	2.48^{abcdef}(9)	30.14^{abc}(4)	30.55^{abcd}(23)
H26	24.09^{a}(1)	7.31^{fgh}(27)	3319^{a}(2)	4.33^{cde}(13)	2.18^{defgh}(23)	29.79^{abc}(6)	45.14^{abcd}(8)
H27	18.90^{ab}(7)	7.78^{cdefgh}(21)	2572^{abc}(4)	4.33^{cde}(14)	2.27^{bcdefgh}(19)	29.07^{abc}(9)	28.12^{bcd}(27)
H28	13.29^{b}(30)	8.80^{abcde}(7)	1586^{c}(29)	4.83^{bcde}(10)	2.41^{abcdef}(12)	27.63^{abcd}(26)	42.59^{abcd}(12)
H29	21.10^{ab}(3)	6.53^{h}(30)	3351^{a}(1)	7.0^{a}(1)	1.93^{h}(30)	29.70^{abc}(7)	31.71^{abcd}(21)
H30	17.34^{ab}(13)	9.38^{a}(3)	1909^{bc}(23)	5.16^{abcd}(6)	2.65^{ab}(3)	28.43^{abcd}(16)	21.53^{d}(30)
Mean	**17.17**	**8.24**	**2167.47**	**4.40**	**2.35**	**28.56**	**39.13**
SE±	**3.64**	**0.64**	**500.62**	**0.88**	**0.17**	**1.48**	**13.24**
%CV	**21.2**	**7.9**	**23.1**	**20.1**	**7.5**	**5.2**	**33.8**
P-value	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

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

Key: YLD = Yield (kg/tree), NTWT = Nut weight (g), NTPCL =Nuts per panicle, NTPT = Nuts per tree, KNWT = Kernel weight (g), %OT = Percentage out turn, CLNBD = Cashew leaf and nut blight disease. Numbers in parentheses indicate hybrid ranking

In the combined analysis, the yield ranged from 13.29kg/tree to 24.09kg/tree with the control AC4 ranking 25th which was not statistically different at P≤0.05 from the rest 23 hybrids that ranked above it (Table 6). Only the highest yielder (H26) was significantly (P≤0.05) better than the control. Hybrid H26 consistently yielded highest at Chambezi and in combined analysis while it ranked eighth at Nachingwea.

4.3.2 Nut weight

At Nachingwea, all hybrids with the exception of H29 and H2 had nut weight greater than the standard weight of 6.5g recommended by cashew breeders in Tanzania (Table 4). The control variety AC4 excelled in nut weight but did not differ significantly (P≤0.05) from hybrid H14, H19, H9, H30, H11, H17, H8, H1, H16, H13, H25, H5, H28 and H12. The lowest nut weight was exhibited by H2 and H29, which were statistically similar to only H7, H18, H23, H27, H21 and H26.

It was interesting to note that all hybrids at Chambezi had nut weight greater than 6.5g (Table 5). The highest nut weight was recorded from H30 which did not differ significantly (P≤0.05) from other 23 hybrids; all those with nut weight above 7.56g while the lowest was observed from H1 (Table 5).

In combined analysis, H19 had the highest nut weight but this was not significantly different at P≤0.05 from other 17 hybrids (Table 6). The lowest nut weight was observed from H29 which was, however, greater than 6.5g.

4.3.3 Nuts per tree

At Nachingwea, the control variety AC4 ranked 24th and differed significantly at P≤0.05 from H29 and H2 that had higher number of nuts per tree (Table 4). H29 recorded the highest number of nuts per tree although it was statistically the same to H2, H26, H5, H27, H4, H18 and H7. The lowest number of nuts per tree was recorded from H14 that was not significantly different (P≤0.05) from 22 other hybrids.

Although H26 had the highest number of nuts per tree, it was statistically similar (P≤0.05) to the other 15 hybrids at Chambezi (Table 5). The control AC4 ranked 22nd and it was statistically similar to 20 other hybrids which ranked higher than it.

Hybrid H29 recorded the highest number of nuts per tree in the combined analysis (Table 6). The hybrid, however, was not statistically different (P≤0.05) from H26, H5, H27, H2, H15, H11, H22, H1 and H24. The control AC4 ranked 27th and differed significantly (P≤0.05) from H29, H26 and H5 that had higher number of nuts per tree. Like at Nachingwea, H14 had the lowest number of nuts per tree in combined analysis.

4.3.4 Nuts per panicle

At Nachingwea H14 had the highest number of nuts per panicle though statistically equal at (P≤0.05) to 25 other hybrids with number of nuts per panicle above 3.66 (Table 4). The lowest number of nuts per panicle was recorded from H7 that was statistically similar to 26 other hybrids; all those with nuts per panicle less than 6.0.

H29 had the highest nuts per panicle at Chambezi that did not differ significantly to H17, H23 and H25 (Table 5). On the other hand H11 recorded the least number of nuts per panicle which was statistically similar ($P \leq 0.05$) to 24 other hybrids.

In the combined analysis H29 had the highest number of nuts per panicle that did not differ significantly ($P \leq 0.05$) from H17, H23, H14, AC4 and H30 (Table 6). H11 had the least number of nuts per panicle like at Chambezi which was statistically similar to 23 other hybrids with nuts per panicle less than 5.16.

4.3.5 Kernel weight

The control variety, AC4, recorded the highest kernel weight at Nachingwea but was statistically similar ($P \leq 0.05$) to H19, H11, H16, H14, H30, H9 and H24 (Table 4). On the other hand, H29 had the least kernel weight which was not statistically different from H2, H21, H27, H26, H22, H10, H18 and H23.

H23 ranked first in kernel weight at Chambezi but did not differ significantly ($P \leq 0.05$) from hybrids with kernel weight ranging between 2.22g to 2.86g. H1 recorded the lowest kernel weight which was statistically similar to hybrids with kernel weight less 2.73g (Table 5).

In the combined analysis, although AC4 had the highest kernel weight, was statistically equal ($P \leq 0.05$) to H19, H30, H24, H8, H23, H9, H17, H25, H16, H11, and H28 (Table 6). H29 which exhibited the lowest kernel weight was statically similar to all hybrids with kernel weight less than 2.328g.

4.3.6 Percentage out turn

At Nachingwea hybrid H24 appeared to perform well in percentage out turn but was not significantly different ($P \leq 0.05$) from 19 other hybrids while H14 recorded the least which was statistically similar to other 26 hybrids (Table 4). H23 had the highest percentage out turn at Chambezi which was statistically equal to other 27 hybrids; all those with percentage out turn above 25.88% (Table 5). On the other hand, the lowest percentage out turn was recorded from H14 which did not differ significantly from 25 other hybrids; all those hybrids with percentage out turn below 30.39%.

In the combined analysis, H23 recorded the highest percentage out turn, which was statistically equal to other 25 hybrids (Table 6). The lowest was recorded from H14 which was statistically similar ($P \leq 0.05$) to 14 other hybrids; all those with percentage out turn below 28.47%. It was interesting to note that all hybrids at Nachingwea, Chambezi and in combined analysis had percentage out turn above 20%, the minimum standard recommended by cashew processors.

4.3.7 Cashew leaf and nut blight disease

At Nachingwea H14 showed the highest disease incidence of 51.39% which did not, however, differ significantly from all hybrids with exception of H27 and H24 (Table 4). The lowest disease incidence of 6.94% was recorded from H24 and did not differ significantly ($P \leq 0.05$) from all hybrids with scores of less than 44.84%.

Most of the hybrids tested at Chambezi were heavily affected by cashew leaf and nut blight disease. The lowest disease incidence was 15.74% recorded in H5 while the highest disease incidence (77.78%) was recorded in H2 (Table 5). In combined analysis, H30 had the lowest incidence (21.53%) which did not differ significantly ($P \leq 0.05$) from 25 other hybrids with scores of less than 51.04%; while H21 recorded the highest incidence (58.10%).

4.4 Effects of Location

With respect to location effect, the results indicated Nachingwea to outperform Chambezi in yield, nuts per tree and nuts per panicle. On the other hand, Chambezi excelled Nachingwea in nut weight, kernel weight and percentage out turn (Table7).

Table 7: Location effects for cashew yield and yield components

Location	YLD(kg/tree)	NTWT(g)	NTPT	NTPCL	KNWT(g)	%OT
Nachingwea	19.59	7.94	2552.05	4.53	2.24	28.28
Chambezi	14.75	8.54	1782.88	4.27	2.45	28.84
Mean	17.17	8.24	2167.46	4.40	2.35	28.56
SE±	0.38	0.06	52.77	0.09	0.01	0.15
P-value	0.001	0.001	0.001	0.05	0.001	0.05

Key: YLD = Yield, NTWT = Nut weight, NTPT = Nuts per tree, NTPCL = Nuts per panicle, KNWT = Kernel weight %OT = Percentage out turn

4.5 Effect of Genotype x Location on the studied agronomic variables

There were profound differences in rankings of the hybrids at the two studied locations for all variables (Table 4 and 5). H4 ranked highest (first) at Nachingwea on yield followed by H30 and H5 while at Chambezi they ranked 23rd (H4), 26th (H30) and 5th (H5). H5 and H29 manifested consistently higher yields at both locations with H5 ranking 3rd at Nachingwea and 5th at Chambezi while H29 ranked 4th at Nachingwea and 6th at Chambezi.

For nut weight, the control variety AC4 had the highest at Nachingwea, followed by H14, H19 and H9 while at Chambezi they ranked 7th, 9th, 2nd and 6th, respectively. Hybrid H9 manifested consistently higher nut weight at both locations. With respect to nuts per tree, H29 ranked first at Nachingwea followed by H2, H26 and H5 while at Chambezi they ranked 5th (H29), 23rd (H2), 1st (H26) and 4th (H5). Hybrids H29, H26 and H5 had consistently higher nuts per tree at both locations. For nuts per panicle, H14 had the highest at Nachingwea, followed by H23 and H30 while at Chambezi they ranked 6th, 3rd and 15th, respectively. On the other hand H23, H17, and H29 manifested consistently higher nuts per panicle at both locations.

AC4 ranked highest (first) at Nachingwea on kernel weight followed by H19, H11 and H16 while at Chambezi they ranked 8th, 3rd, 19th and 12th, respectively. H19 had consistently higher kernel weight at both locations. For percentage out turn H24 had the highest (first) at Nachingwea, followed by H7, H2 and H29 while at Chambezi they ranked 17th, 6th, 4th and 8th, respectively. H2 manifested consistently higher percentage out turn at both locations.

With respect to cashew leaf and nut blight disease, H24 recorded the lowest disease incidence at Nachingwea followed by H27, H26 and H22 while at Chambezi they ranked 15th (H24), 20th (H27), 27th (H22) and 3rd (H26). On the other hand H22 consistently recorded the lowest disease incidence at both locations.

4.6 Nutritional Characteristics of the Studied Hybrids

4.6.1 ANOVA for the studied nutritional variables

Table 8 shows analysis of variance results for the nutritional variables. Significant ($P \leq 0.05$) varietal effects as well as location and interaction effects were observed for crude protein, fat, potassium, copper, magnesium, iron, zinc and vitamin C. No significant variation was observed in terms of calcium content except for the hybrids at Nachingwea. Likewise, there was no significant variation in terms of sodium content among the treatments.

Table 8: Analysis of variance for nutritional variables in cashew hybrids grown at Nachingwea, Chambezi and in the combined analysis

S.V	DF	Mean square ANOVA values									
		%CP	%Fat	%K	Ca	Na	Mg	Cu	Zn	Fe	Vit C
Nachingwea											
REP	2	0.2987	0.00029	0.0032**	89799	19748	0.00059	0.0057*	0.0029*	0.0039	0.1048
HYBRID	29	20.27***	112***	0.0127***	47297*	4402	0.0065***	119***	73.9***	199***	319.88***
Error	58	0.1632	0.00052	0.0004	19774	4534	0.0002	0.0011	0.00081	0.0013	0.1036
Total	89										
Chambezi											
REP	2	0.246	1.561	0.0230*	40034	9363	0.00056	0.0009	0.0012	0.0045*	0.134
HYBRID	29	8.84***	56.007***	0.0041	33043	6144	0.003***	96.7***	21.2***	45.5***	620.09***
Error	58	1.79	1.571	0.0056	47430	3264	0.00085	0.00091	0.0006	0.00098	0.1948
Total	89										
Combined analysis											
S.V	**DF**	**%CP**	**%FAT**	**%K**	**Ca**	**Na**	**Mg**	**Cu**	**Zn**	**Fe**	**Vit C**
REP	2	0.042	0.7626	0.0047	22365	27777***	0.00067	0.005**	0.004**	0.0069**	0.0016
HYBRID	29	14.126***	79.36***	0.01***	44851	5392	0.0043***	129***	59.3***	154***	427.38***
LOCATION	1	98.39***	343.44***	1.236***	88516	2378	0.4650***	35.3***	3.39***	640***	78.619***
LOCATION*HYBRID	29	14.98***	89.19***	0.0067**	35489	5154	0.0052***	86.8***	35.8***	89.9***	512.58***
Error	118	0.9715	0.786	0.0033	34854	3855	0.00053	0.001	0.0007	0.001	0.1507
Total	179										

Key: S.V = Source of variation, DF = Degrees of freedom, CP = Crude Protein (%), K = Potassium (%), Ca = Calcium, Na = Sodium, Mg= Magnesium, Cu = Copper, Zn = Zinc, Fe = Iron, Vit = Vitamin, * Significant at $P \leq 0.05$, ** significant at $P \leq 0.01$, *** significant at $P \leq 0.001$

4.6.2 Genotypic effects

4.6.2.1 Crude protein

At Nachingwea, H14 recorded highest crude protein although it was statistically similar to H12, H15 and H27 (Table 9). Hybrid with the lowest crude protein was H26 and was statistically similar to only H7 ($P \leq 0.05$). At Chambezi, H18 recorded the highest crude protein but was not significantly different ($P \leq 0.05$) from 19 other hybrids (Table 10). These hybrids were H16, H25, H6, H15, H30, H1, H11, H2, H24, H21, H13, AC4, H22, H17, H26, H10, H12, H29 and H27. In the combined analysis, treatment H15 had highest crude protein though was statistically similar ($P \leq 0.05$) to H16, H18, H12, H1, H14, H27, H30, H17, H6 and H25 (Table 11). Hybrid H23 gave the lowest crude protein but was statistically equal to H7, H26, H28, H11 and H8.

4.6.2.2 Fat

At Nachingwea, H7 recorded highest fat percentage (50.1%) which was significantly different ($P \leq 0.05$) from all other hybrids (Table 9). Lowest fat percentage (29.46%) was recorded on H17. The control variety AC4 ranked third with 47.55% and differed significantly from other hybrids. H23 gave highest fat content (49.34%) at Chambezi but was statistically the same ($P \leq 0.05$) as H13, H25, H16, H21, H8, H27, AC4 and H22 (Table 10). On the other hand the lowest fat content was obtained from H15 which did not differ significantly from H7. In combined analysis, AC4 gave the highest fat content though was statistically the same ($P \leq 0.05$) as H10, H16, H25, H22 and H24 (Table 11). The lowest content was recorded by H26 which did not however differ significantly from H28, H17 and H12.

Table 9: Nutritional content and quality of cashew nuts hybrids at Nachingwea

Hybrid	%CP	% Fat	%K	%Mg	Cu(ppm)	Fe(ppm)	Vit C(mg/100ml)	Zn(ppm)
H1	21.07^{de}(8)	43.77^{k}(11)	0.611^{ab}(2)	0.2189^{cd}(7)	16.19^{k}(20)	55.6^{a}(1)	203.9^{f}(11)	43.46^{c}(3)
H2	16.65^{mno}(25)	38.22^{p}(17)	0.48^{defgh}(14)	0.209^{cdef}(16)	14.55^{m}(24)	43.81^{g}(9)	210.9^{b}(4)	42.03^{f}(8)
H3	20.03^{efgh}(11)	45.08^{i}(9)	0.4485^{fghijk}(21)	0.1833^{cdef}(27)	17.83^{h}(16)	35.96^{i}(21)	194^{k}(22)	37.26^{p}(21)
H4	19.14^{hijk}(15)	38.01^{r}(19)	0.4767^{defghi}(15)	0.1996^{cdef}(22)	18.65^{g}(11)	32.01^{j}(28)	211^{b}(3)	33.91^{s}(24)
H5	22^{bcd}(5)	38.87^{o}(16)	0.5167^{cde}(7)	0.1815^{def}(28)	15.37^{l}(23)	28.09^{k}(29)	195.3^{j}(21)	32.95^{t}(25)
H6	18.52^{ijkl}(18)	43.08^{l}(12)	0.6467^{a}(1)	0.4033^{a}(1)	4.7^{r}(30)	44.18^{f}(8)	204.9^{ef}(9)	47.94^{a}(1)
H7	14^{qr}(29)	50.1^{a}(1)	0.46^{efghij}(19)	0.2085^{cdef}(17)	14.55^{m}(25)	39.88^{h}(14)	196.9^{i}(17)	38.69^{m}(15)
H8	18.03^{kl}(20)	37.42^{s}(20)	0.3885^{kl}(29)	0.171^{ef}(29)	12.91^{n}(26)	35.95^{i}(22)	193.8^{kl}(23)	27.23^{w}(30)
H9	21.64^{cd}(6)	43.01^{l}(13)	0.4485^{fghijk}(22)	0.1893^{cdef}(26)	6.34^{q}(29)	43.8^{g}(10)	196.9^{i}(18)	30.57^{v}(27)
H10	19.61^{ghij}(14)	48.68^{b}(2)	0.41^{ijk}(25)	0.1989^{cdef}(23)	16.19^{k}(21)	32.02^{j}(24)	195.4^{j}(20)	30.57^{v}(28)
H11	15.21^{pq}(28)	36.23^{t}(21)	0.4813^{defgh}(12)	0.2173^{cde}(8)	12.08^{o}(27)	55.6^{a}(2)	200.8^{gh}(14)	42.98^{d}(5)
H12	23.08^{ab}(2)	33.25^{w}(25)	0.5052^{cdef}(8)	0.2266^{cd}(4)	21.11^{e}(5)	55.31^{b}(4)	206.9^{cd}(7)	42.98^{d}(6)
H13	18.35^{jkl}(19)	32.66 ^{x}(26)	0.4214^{hijk}(24)	0.207^{cdef}(18)	16.19^{k}(22)	32.02^{j}(25)	214.7^{a}(1)	36.3^{q}(22)
H14	23.4^{a}(1)	46.09^{f}(6)	0.4693^{defghi}(17)	0.1972^{cdef}(24)	17.83^{h}(12)	39.88^{h}(15)	167.3^{p}(30)	42.51^{e}(7)
H15	22.79^{abc}(3)	45.34^{h}(8)	0.43^{ghijk}(23)	0.2101^{cdef}(14)	7.16^{p}(28)	39.88^{h}(16)	189.6^{m}(26)	43.46^{c}(4)
H16	20.8^{defg}(10)	45.69^{g}(7)	0.3392^{l}(30)	0.1709^{f}(30)	16.19^{k}(19)	32.02^{j}(27)	181.7^{o}(29)	30.57^{v}(29)
H17	21.12^{de}(7)	29.46^{z}(30)	0.4804^{defgh}(13)	0.2297^{c}(3)	35.06^{a}(1)	55.6^{a}(3)	201.3^{g}(12)	40.6^{j}(12)
H18	19.75^{fghi}(12)	39.79^{n}(15)	0.4591^{efghij}(20)	0.2212^{cd}(5)	21.11^{e}(7)	47.74^{e}(7)	211.5^{b}(2)	41.55^{h}(10)
H19	20.93^{def}(9)	34.89^{u}(22)	0.53^{cd}(4)	0.2057^{cdef}(19)	17.83^{h}(13)	43.81^{g}(11)	207.1^{c}(6)	38.21^{n}(17)
AC4	17.39^{lmn}(24)	47.55^{c}(3)	0.4911^{defg}(11)	0.2^{cdef}(21)	16.53^{j}(18)	43.81^{g}(12)	197.1^{i}(16)	40.12^{k}(13)
H21	18.71^{ijk}(16)	34.84^{u}(23)	0.3975^{jkl}(27)	0.1923^{cdef}(25)	22.75^{d}(4)	35.95^{i}(23)	183.6 ^{n}(28)	31.53^{u}(26)
H22	18.66^{ijkl}(17)	46.2^{e}(5)	0.4094^{ijk}(26)	0.2011^{cdef}(20)	26.86^{c}(3)	39.88^{h}(17)	205.9^{de}(8)	39.16^{l}(14)
H23	15.83^{op}(27)	34.36^{uv}(24)	0.5052^{cdef}(9)	0.2104^{cdef}(13)	21.11^{e}(6)	43.81^{g}(13)	201.1^{g}(13)	37.73^{o}(19)
H24	16.56^{no}(26)	46.81^{d}(4)	0.4693^{defghi}(18)	0.2144^{cdef}(10)	17.83^{h}(14)	28.09^{k}(30)	204.6^{f}(10)	38.69^{m}(16)
H25	17.95^{klm}(22)	44.48^{j}(10)	0.5686^{bc}(3)	0.35^{b}(2)	18.65^{g}(9)	48.19^{d}(6)	196.6^{i}(19)	41.78^{g}(9)
H26	13.59^{r}(30)	30.09^{y}(27)	0.3975^{jkl}(28)	0.2109^{cdef}(12)	17.01^{i}(17)	32.02^{j}(26)	199.8^{h}(15)	41.07^{i}(11)
H27	22.74^{abc}(4)	41.22^{m}(14)	0.53^{cd}(5)	0.2111^{cdef}(11)	17.83^{h}(15)	39.88^{h}(18)	192.8^{l}(24)	37.73^{o}(20)
H28	17.93^{klm}(23)	32.26^{xy}(28)	0.5035^{cdef}(10)	0.2173^{cde}(9)	18.65^{g}(10)	39.89^{h}(19)	184.4^{n}(27)	44.89^{b}(2)
H29	18^{kl}(21)	38.14^{q}(18)	0.4767^{defghi}(16)	0.21^{cdef}(15)	31.78^{b}(2)	39.88^{h}(20)	207.8^{c}(5)	38.21^{n}(18)
H30	19.64^{fghij}(13)	29.73^{yz}(29)	0.52^{cde}(6)	0.2201^{cd}(6)	20.29^{f}(8)	51.68^{c}(5)	189.8^{m}(25)	35.35^{r}(23)
Overall Mean	**19.1**	**39.84**	**0.48**	**0.22**	**17.7**	**41.21**	**198.25**	**38.33**
SE±	**0.404**	**0.023**	**0.021**	**0.014**	**0.034**	**0.036**	**0.322**	**0.029**
%CV	**2.1**	**0.1**	**4.4**	**6.7**	**0.2**	**0.1**	**0.2**	**0.1**
P-value	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Tukey's Test. Key: CP = Crude Protein (%), K = Potassium (%), Mg= Magnesium, Cu = Copper, Zn = Zinc, Fe = Iron, Vit = Vitamin

Table 10: Nutritional content and quality of cashew nuts hybrids at Chambezi

Hybrid	%CP	%Fat	% K	%Mg	Cu(ppm)	Fe(ppm)	Vit C(mg/100ml)	Zn(ppm)
H1	21.85^{abcde}(7)	42.5^{efghij}(18)	0.71^{a}(2)	0.22^{c}(30)	21.33^{e}(5)	44.18^{f}(18)	210.6^{e}(7)	36.39^{l}(21)
H2	21.81^{abcde}(9)	36.49^{lm}(28)	0.64^{a}(13)	0.28^{abc}(26)	19.2^{g}(8)	48.19^{d}(8)	196.7^{k}(18)	34.85^{o}(28)
H3	19.53^{bcdef}(21)	42.9^{defghi}(15)	0.64^{a}(14)	0.34^{ab}(9)	14.95^{k}(22)	44.18^{f}(19)	178^{q}(28)	38.7^{i}(14)
H4	18.55^{def}(26)	40.82^{fghijk}(19)	0.67^{a}(7)	0.28^{abc}(27)	17.08^{i}(15)	44.22^{f}(15)	167.6^{s}(30)	36.01^{m}(23)
H5	18.39^{ef}(27)	42.82^{defghi}(17)	0.61^{a}(25)	0.31^{abc}(20)	12.83^{l}(23)	36.14^{i}(30)	199.5^{j}(15)	35.61^{n}(27)
H6	22.73^{abcd}(4)	39.82^{hijklm}(22)	0.62^{a}(22)	0.28^{abc}(28)	17.83^{h}(14)	44.19^{f}(16)	199.5^{j}(16)	37.16^{k}(19)
H7	19.27^{bcdef}(24)	35.79^{mn}(29)	0.61^{a}(26)	0.2667^{bc}(29)	23.45^{d}(4)	46.18^{e}(14)	188.8^{n}(25)	37.55^{j}(18)
H8	19.45^{bcdef}(22)	46.69^{abcd}(6)	0.56^{a}(29)	0.29^{abc}(25)	8.59^{n}(25)	54.22^{a}(1)	191.2^{m}(23)	36.39^{l}(20)
H9	18.1^{ef}(29)	39.04^{ijklm}(24)	0.63^{a}(18)	0.3033^{abc}(23)	8.58^{n}(26)	40.16^{h}(27)	213.1^{d}(5)	32.54^{q}(30)
H10	20.3^{abcdef}(17)	44.84^{bcdef}(10)	0.64^{a}(15)	0.3367^{ab}(10)	8.58^{n}(27)	44.18^{f}(17)	205.3^{gh}(12)	36.39^{l}(22)
H11	21.81^{abcde}(8)	43.7^{defgh}(14)	0.62^{a}(23)	0.31^{abc}(19)	19.2^{g}(9)	46.18^{e}(10)	171.4^{r}(29)	39.86^{f}(6)
H12	20.24^{abcdef}(18)	39.39^{ijklm}(23)	0.591^{a}(28)	0.34^{ab}(5)	19.2^{g}(10)	46.18^{e}(11)	186.6^{o}(26)	44.48^{a}(1)
H13	21.35^{abcdef}(12)	48.61^{ab}(2)	0.6981^{a}(3)	0.34^{ab}(6)	8.58^{n}(28)	48.19^{d}(5)	199^{j}(17)	38.7^{i}(13)
H14	19.33^{bcdef}(23)	38.42^{klm}(26)	0.5984^{a}(27)	0.3^{abc}(24)	17.08^{i}(16)	46.18^{e}(12)	210.2^{e}(8)	36.01^{m}(24)
H15	22.4^{abcde}(5)	31.77^{n}(30)	0.6316^{a}(17)	0.3367^{ab}(11)	17.07^{i}(18)	42.17^{g}(20)	196.4^{k}(19)	33.31^{p}(29)
H16	23.38^{ab}(2)	47.74^{abc}(4)	0.59^{a}(30)	0.33^{ab}(13)	7.52^{o}(30)	42.17^{g}(23)	211.4^{e}(6)	37.55^{j}(15)
H17	20.35^{abcdef}(15)	40.68^{ghijk}(20)	0.62^{a}(24)	0.32^{ab}(15)	20.27^{f}(7)	50.2^{c}(3)	208.1^{f}(9)	39.86^{f}(7)
H18	24.23^{a}(1)	40.3^{ghijkl}(21)	0.65^{a}(10)	0.3367^{ab}(12)	17.08^{i}(17)	46.18^{e}(13)	204.5^{h}(13)	36.01^{m}(25)
H19	18.11^{ef}(28)	44.73^{bcdef}(11)	0.68^{a}(6)	0.3033^{abc}(21)	16.02^{j}(20)	42.17^{g}(22)	213.6^{d}(4)	39.47^{g}(10)
AC4	20.77^{abcdef}(13)	46.22^{abcde}(8)	0.63^{a}(19)	0.3033^{abc}(22)	24.52^{c}(3)	48.19^{d}(7)	179.5^{p}(27)	37.55^{j}(16)
H21	21.61^{abcdef}(11)	47.74^{abc}(5)	0.639^{a}(16)	0.37^{a}(1)	8.58^{n}(29)	42.17^{g}(25)	196.2^{k}(20)	39.09^{h}(11)
H22	20.53^{abcdef}(14)	46.19^{abcde}(9)	0.6981^{a}(4)	0.36^{ab}(2)	19.2^{g}(11)	48.19^{d}(6)	200.9^{i}(14)	39.09^{h}(12)
H23	17.43^{f}(30)	49.34^{a}(1)	0.6834^{a}(5)	0.36^{ab}(3)	9.64^{m}(24)	52.21^{b}(2)	232.5^{a}(1)	39.86^{f}(8)
H24	21.63^{abcdef}(10)	43.87^{cdefg}(13)	0.6538^{a}(9)	0.35^{ab}(4)	25.58^{b}(2)	42.17^{g}(26)	219.5^{b}(2)	39.86^{f}(9)
H25	22.89^{abc}(3)	48.14^{ab}(3)	0.65^{a}(11)	0.34^{ab}(7)	17.01^{i}(19)	42.17^{g}(21)	192.2^{lm}(22)	42.55^{b}(2)
H26	20.33^{abcdef}(16)	38.69^{jklm}(25)	0.66^{a}(8)	0.34^{ab}(8)	16.02^{j}(21)	40.16^{h}(28)	190.9^{m}(24)	40.24^{e}(5)
H27	19.92^{abcdef}(20)	46.65^{abcd}(7)	0.6206^{a}(21)	0.32^{ab}(16)	21.33^{e}(6)	42.17^{g}(24)	193.5^{l}(21)	37.55^{j}(17)
H28	18.89^{cdef}(25)	37.49^{klm}(27)	0.65^{a}(12)	0.33^{ab}(14)	19.2^{g}(12)	48.19^{d}(4)	206.2^{g}(11)	41.4^{d}(4)
H29	20.01^{abcdef}(19)	42.82^{defghi}(16)	0.63^{a}(20)	0.32^{ab}(17)	19.2^{g}(13)	40.16^{h}(29)	216.3^{c}(3)	41.77^{c}(3)
H30	22.29^{abcde}(6)	43.99^{cdefg}(12)	0.72^{a}(1)	0.32^{ab}(18)	29.83^{a}(1)	48.19^{d}(9)	208^{f}(10)	36.01^{m}(26)
Overall Mean	**20.58**	**42.61**	**0.64**	**0.32**	**16.82**	**44.98**	**199.57**	**38.06**
SE±	**1.34**	**1.253**	**0.075**	**0.029**	**0.03**	**0.031**	**0.441**	**0.025**
%CV	**6.5**	**2.9**	**11.7**	**9.2**	**0.2**	**0.1**	**0.2**	**0.1**
P-value	**0.001**	**0.001**	**0.812**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Tukey's Test. Key: CP = Crude Protein (%), K = Potassium (%), Mg= Magnesium, Cu = Copper, Zn = Zinc, Fe = Iron, Vit = Vitamin

Table 11: Nutritional content and quality of cashew nuts hybrids in combined analysis

Hybrid	%CP	%Fat	%K	%Mg	Cu(ppm)	Fe(ppm)	Vit C(mg/100mL)	Zn(ppm)
H1	21.46^{abcd}(5)	43.13^{cd}(9)	0.66^{a}(1)	0.22^{d}(30)	18.76^{k}(12)	49.89^{d}(5)	207.2^{de}(6)	39.92^{i}(9)
H2	19.23^{efghi}(20)	37.36^{kl}(25)	0.56^{abcd}(13)	0.24^{bcd}(26)	16.88^{n}(17)	46^{g}(9)	203.8^{g}(10)	38.44^{n}(17)
H3	19.78^{defghi}(17)	43.99^{bc}(7)	0.54^{abcd}(21)	0.26^{bcd}(19)	16.39^{p}(19)	40.07^{op}(22)	186^{r}(30)	37.98^{p}(20)
H4	18.84^{fghij}(24)	39.41^{ij}(23)	0.57^{abcd}(9)	0.24^{bcd}(27)	17.86^{l}(13)	38.12^{r}(25)	189.3^{op}(26)	34.96^{u}(25)
H5	$20.2^{bcdefghi}$(12)	40.84^{fghi}(17)	0.56^{abcd}(10)	0.25^{bcd}(25)	14.1^{s}(23)	32.12^{v}(30)	197.4^{k}(15)	34.28^{v}(26)
H6	$20.62^{abcdefgh}$(10)	41.45^{defgh}(14)	0.63^{ab}(2)	0.34^{a}(2)	11.26^{w}(28)	44.19^{j}(12)	202.2^{h}(12)	42.55^{c}(3)
H7	16.63^{k}(29)	42.95^{cde}(10)	0.54^{abcd}(23)	0.24^{bcd}(28)	19^{j}(10)	43.03^{l}(16)	192.9^{n}(23)	38.12^{o}(19)
H8	18.74^{ghijk}(25)	42.06^{cdef}(12)	0.47^{cd}(29)	0.23^{cd}(29)	10.75^{x}(29)	45.09^{i}(11)	192.5^{n}(24)	31.81^{y}(29)
H9	$19.87^{cdefghi}$(15)	41.02^{efghi}(16)	0.54^{abcd}(22)	0.25^{bcd}(24)	7.46^{y}(30)	41.98^{m}(18)	205^{f}(8)	31.56^{z}(30)
H10	$19.96^{bcdefghi}$(14)	46.76^{a}(2)	0.53^{bcd}(27)	0.27^{bc}(15)	12.38^{t}(25)	38.1^{r}(26)	200.3^{i}(13)	33.48^{x}(28)
H11	18.51^{hijk}(26)	39.96^{ghij}(21)	0.55^{abcd}(18)	0.26^{bcd}(18)	15.64^{q}(21)	50.89^{b}(2)	186.1^{r}(29)	41.42^{e}(5)
H12	21.66^{abcd}(4)	36.32^{lmn}(27)	0.55^{abcd}(20)	0.28^{b}(4)	20.16^{g}(7)	50.75^{c}(3)	196.7^{k}(16)	43.73^{a}(1)
H13	$19.85^{cdefghi}$(16)	40.64^{fghi}(18)	0.56^{abcd}(14)	0.27^{bc}(12)	12.38^{t}(24)	40.11^{o}(21)	206.8^{e}(7)	37.5^{r}(22)
H14	21.36^{abcde}(6)	42.26^{cdef}(11)	0.53^{abcd}(24)	0.25^{bcd}(23)	17.45^{m}(15)	43.03^{l}(15)	188.7^{pq}(27)	39.26^{j}(11)
H15	22.59^{a}(1)	38.55^{jk}(24)	0.53^{abcd}(25)	0.27^{bc}(13)	12.11^{u}(26)	41.03^{n}(19)	193^{n}(22)	38.38^{n}(18)
H16	22.09^{ab}(2)	46.72^{a}(3)	0.46^{d}(30)	0.25^{bcd}(22)	11.86^{v}(27)	37.09^{s}(27)	196.6^{k}(17)	34.06^{w}(27)
H17	$20.73^{abcdefg}$(9)	35.07^{mn}(28)	0.55^{abcd}(19)	0.27^{bc}(10)	27.66^{a}(1)	52.9^{a}(1)	204.7^{f}(9)	40.23^{g}(7)
H18	21.99^{abc}(3)	40.04^{ghij}(20)	0.55^{abcd}(15)	0.28^{b}(8)	19.09^{i}(9)	46.96^{f}(7)	208^{d}(5)	38.78^{m}(16)
H19	19.52^{defghi}(19)	39.81^{hij}(22)	0.61^{ab}(5)	0.25^{bcd}(20)	16.93^{n}(16)	42.99^{l}(17)	210.4^{c}(4)	38.84^{l}(13)
AC4	19.08^{fghij}(22)	46.88^{a}(1)	0.56^{abcd}(12)	0.25^{bcd}(21)	20.53^{f}(6)	46^{g}(8)	188.3^{q}(28)	38.83^{lm}(14)
H21	$20.16^{bcdefghi}$(13)	41.29^{defghi}(15)	0.52^{bcd}(28)	0.28^{b}(6)	15.66^{q}(20)	39.06^{q}(24)	189.9^{o}(25)	35.31^{t}(24)
H22	19.59^{defghi}(18)	46.19^{a}(5)	0.55^{abcd}(16)	0.28^{b}(7)	23.03^{d}(4)	44.04^{k}(14)	203.4^{g}(11)	39.13^{k}(12)
H23	16.63^{k}(30)	41.85^{defg}(13)	0.59^{abc}(6)	0.29^{b}(3)	15.38^{r}(22)	48.01^{e}(6)	216.8^{a}(1)	38.8^{lm}(15)
H24	19.09^{fghij}(21)	45.34^{ab}(6)	0.56^{abcd}(11)	0.28^{b}(5)	21.7^{e}(5)	35.13^{u}(29)	212.1^{b}(2)	39.27^{j}(10)
H25	$20.42^{abcdefghi}$(11)	46.31^{a}(4)	0.61^{ab}(4)	0.35^{a}(1)	17.83^{l}(14)	45.18^{h}(10)	194.4^{m}(20)	42.16^{d}(4)
H26	16.96^{jk}(28)	34.39^{n}(30)	0.53^{bcd}(26)	0.28^{b}(9)	16.51^{o}(18)	36.09^{t}(28)	195.3^{l}(18)	40.66^{f}(6)
H27	21.33^{abcde}(7)	43.93^{bc}(8)	0.58^{abcd}(8)	0.27^{bc}(16)	19.58^{h}(8)	41.03^{n}(20)	193.1^{n}(21)	37.64^{q}(21)
H28	18.41^{ijk}(27)	34.88^{n}(29)	0.58^{abcd}(7)	0.27^{bcd}(11)	18.93^{j}(11)	44.04^{k}(13)	195.3^{l}(19)	43.15^{b}(2)
H29	19^{fghij}(23)	40.48^{fghij}(19)	0.55^{abcd}(17)	0.27^{bc}(17)	25.49^{b}(2)	40.02^{p}(23)	212^{b}(3)	39.99^{h}(8)
H30	20.96^{abcdef}(8)	36.86^{klm}(26)	0.62^{ab}(3)	0.27^{bc}(14)	25.06^{c}(3)	49.93^{d}(4)	198.9^{j}(14)	35.68^{s}(23)
Overall Mean	19.84	41.23	0.56	0.27	17.26	43.1	198.9	38.2
SE±	0.569	0.512	0.033	0.013	0.032	0.034	0.388	0.027
%CV	5	2.2	10.4	8.6	0.2	0.1	0.2	0.1
P-value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

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

Key: CP = Crude Protein (%), K = Potassium (%), Mg= Magnesium, Cu = Copper, Zn = Zinc, Fe = Iron, Vit = Vitamin

4.6.2.3 Potassium

Genotype H6 recorded highest potassium content at Nachingwea though statistically ($P \leq 0.05$) was similar to H1 (Table 9). The lowest was observed from hybrid H16 which was statistically similar to H8, H26 and H21. At Chambezi, there was no statistical ($P \leq 0.05$) significance of the potassium content variation (Table 10). In the combined analysis hybrid H1 recorded highest potassium but was statistically similar ($P \leq 0.05$) to 24 other hybrids; H6, H30, H25, H19, H23, H28, H27, H4, H5, H24, AC4, H2, H13, H18, H22, H29, H11, H17, H12, H3, H9, H7, H14 and H15 (Table 11).

4.6.2.4 Magnesium

H6 recorded highest magnesium content at Nachingwea which was significantly different from the rest hybrids (Table 9). Lowest magnesium content recorded was from H16 which, however, was statistically ($P \leq 0.05$) the same as H2, H3, H4, H5, H7, H8, H9, H10, H13, H14, H15, H19, AC4, H21, H22, H23, H24, H26, H27 and H29. At Chambezi H21 recorded highest magnesium content but this was statistically similar to all hybrids except H1 and H7 (Table 10). The combined analysis showed H25 to give higher magnesium content although it did not significantly differ from H6 (Table 11). H1 gave the lowest content as it was observed at Chambezi but was statistically ($P \leq 0.05$) similar to H2, H3, H4, H5, H7, H8, H9, H11, H14, H16, H19, AC4 and H28.

4.6.2.5 Copper

At Nachingwea, H17 gave the highest copper content (35.06%) which differed significantly ($P \leq 0.05$) from contents for the rest of the hybrids while H6 recorded the lowest content and differed significantly from other hybrids (Table 9). At Chambezi, H30 recorded the highest copper content (29.83%), which differed significantly from all the other hybrids (Table 10). Hybrid H16 recorded the lowest content, which also differed significantly ($P \leq 0.05$) from the rest of the hybrids. Results from combined analysis indicated H17 to have given the highest copper content (27.66%) while H9 gave the lowest (7.46%).

4.6.2.6 Iron

At Nachingwea, H1 had the highest iron content although it did not differ significantly ($P \leq 0.05$) from contents for H11 and H17 (Table 9). The lowest iron content was observed from H24 which was statistically similar to H5. At Chambezi, H8 recorded the highest iron content which differed significantly from the rest of hybrids (Table 10). The lowest was observed in H5, which also differed significantly ($P \leq 0.05$) from the rest of the hybrids. From combined analysis, H17 had the highest iron content that differed significantly ($P \leq 0.05$) from the rest of the hybrids while H5 gave the lowest iron content (Table 11).

4.6.2.7 Vitamin C

Hybrid H13 had the highest vitamin C content at Nachingwea and differed significantly ($P \leq 0.05$) from rest of the hybrids (Table 9). On the other hand, H14 recorded the lowest vitamin C content. H23 gave the highest vitamin C content at

Chambezi, which was significantly ($P \leq 0.05$) different from the rest of the hybrids (Table 10). H4 on the other hand gave the lowest vitamin C content at Chambezi and it was statistically different ($P \leq 0.05$) from the rest of hybrids. In the combined analysis H23 had the highest vitamin C content which was significantly different from the rest of the hybrids (Table 11). On the other hand, H3 gave the lowest vitamin C content but was not significantly different from H11.

4.6.2.8 Zinc

At Nachingwea site, H6 recorded the highest zinc content which differed significantly ($P \leq 0.05$) from the rest of the hybrids while H8 gave the lowest content (Table 9). H12 outperformed the rest of hybrids at Chambezi as it differed significantly ($P \leq 0.05$) from all hybrids while H9 recorded the lowest zinc content (Table 10). In combined analysis, H12 recorded the highest zinc content which differed significantly from the rest of the treatments (Table 11). Hybrid H9 gave the lowest zinc content and was significantly ($P \leq 0.05$) different from the other hybrids.

4.6.3 Effect of location on the studied nutritional variables

With respect to effect of location on the nutritional variables, it was observed that Nachingwea kernels were richer than those of Chambezi in zinc and copper while on the other hand Chambezi kernels were richer in the rest of nutritional variables namely crude protein, fat, potassium, magnesium and iron contents.

Table 12: Effects of location on studied nutritional variables

Location	%CP	%Fat	%K	%Mg	Cu(ppm)	Fe(ppm)	Zn(ppm)	Vit C (mg/100mL)
Nachingwea	19.1	39.84	0.48	0.22	17.7	41.21	38.33	198.25
Chambezi	20.58	42.61	0.64	0.32	16.82	44.98	38.06	199.57
Mean	19.84	41.225	0.56	0.27	17.26	43.095	38.195	198.91
SE±	0.147	0.132	0.009	0.003	0.005	0.005	0.004	0.058
P-value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Key: CP = Crude protein, K = Potassium, Mg = Magnesium, Fe = Iron, Zn = Zinc, Vit = vitamin

4.6.4 Effect of Genotype x Location on the nutritional variables

There were profound differences in rankings of the hybrids at the two studied locations for all variables (Table 9 and 10). With respect to crude protein, H14 had the highest crude protein at Nachingwea, followed by H12 and H15 while at Chambezi they ranked 23rd, 18th and 5th, respectively. H15 manifested consistently higher crude protein at both locations with ranking 3rd at Nachingwea and 5th at Chambezi. For fat H7 had the highest content at Nachingwea, followed by H10, AC4 and H24 while at Chambezi they ranked 29th, 10th, 8th and 13th, respectively.

Similarly for potassium content H6 ranked highest (first) at Nachingwea followed by H1, H25 and H19 while at Chambezi they ranked 22nd (H6), 2nd (H1), 11th (H25) and 6th (H19). Hybrids H1 and H19 manifested consistently higher content at both locations. For magnesium content, H6 had the highest at Nachingwea, followed by H25, H17 and H12 while at Chambezi they ranked 28th, 7th, 15th and 5th, respectively. H12 recorded consistently higher magnesium content at both locations.

With respect to copper content, H17 recorded the highest content at Nachingwea, followed by H29, H22 and H21 while at Chambezi they ranked 7th, 13th, 11th and 29th, respectively. Similarly for iron content, H1 had the highest content (first) at Nachingwea, followed by H11, H17 and H12 while at Chambezi they ranked 18th, 10th, 3rd and 11th respectively. On the other hand H17 manifested consistently higher iron content by ranking third at both locations.

H13 had the highest vitamin C content at Nachingwea, followed by H18, H4 and H2 while at Chambezi they ranked 17th (H13), 13th (H18), 30th (H4) and 18th (H2). Similarly for zinc content, H6 ranked highest (first) at Nachingwea followed by H28, H1 and H15 while at Chambezi they ranked 19th, 4th, 21st and 29th, respectively. H28 manifested consistently higher zinc content at both locations.

4.7 Genetic Correlations among Cashew Yield Components at Nachingwea and Chambezi

The correlation coefficients among cashew yield components are presented in Tables (13 to 15). The genotypic correlations in general were slightly higher than corresponding phenotypic correlations but in some cases they were identical. The correlations were estimated through Pearson correlation analysis. Reference is hereby made only to genotypic correlations in order to avoid unnecessary repetitions. At Nachingwea, highly significant positive correlations (r = 0.7883***) were observed between yield and nuts per tree. The results also revealed highly significant negative correlation (r = -0.719***) between nut weight and nuts per tree, nut weight and percentage out turn (r = -0.46***) and also between nuts per tree and kernel

weight (r = -0.611***). Highly significant positive correlation (r = 0.887***) also existed between nut weight and kernel weight while positive and weakly significant correlation (r = 0.249*) existed between percentage out turn and yield
At Chambezi, highly significant positive correlations were observed between yield and nuts per tree (r = 0.9601***) and percentage out turn (r = 0.4705***) respectively.

It was also observed at Chambezi that, highly positive significant correlations existed between nut weight and kernel weight (r = 0.922***), nut weight and percentage out turn (r = 0.583***), nuts per tree and percentage out turn (r = 0.45***), between kernel weight and percentage out turn (r = 0.771***) and between percentage out turn and nuts per panicle (r = 0.346***).

Table 15 shows genotypic and phenotypic correlation results for the combined analysis data. Positive highly significant correlations were observed between yield and nuts per tree (r = 0.9262***); percentage out turn (r = 0.4298***) and nuts per panicle (r = 0.1938**), respectively. Moreover, highly positive significant correlation existed between nut weight and kernel weight (r = 0.926***), nut weight and percentage out turn (r = 0.49***), nut weight and nuts per panicle (r = 0.223**), nuts per tree and percentage out turn (r = 0.414***), nuts per tree and nuts per panicle (r = 0.195**). Moreover, positive significant correlations were observed between kernel weight and percentage out turn (r = 0.677***), kernel weight and nuts per panicle (r = 0.199**) and percentage out turn and nuts per panicle (r = 0.296***).

A significant negative correlation (r = -0.226**) existed in the combined analysis between nut weight and nuts per tree. Nuts per tree, percentage out turn and yield were consistently significant and positively correlated among themselves at genotypic and phenotypic levels at all locations.

Table 13: Correlations for yield and yield components of cashew hybrids at Nachingwea

	YLD	NTWT	NTPT	KNWT	%OT	NTPCL
YLD	1.000					
NTWT	-0.1959 -0.1954	1.000				
NTPT	0.7883*** 0.7872***	-0.719*** -0.719***	1.000			
KNWT	-0.1056 -0.1038	0.887*** 0.887***	-0.611*** -0.610***	1.000		
%OT	0.2499* 0.2490*	-0.46*** -0.46***	0.411*** 0.411***	-0.034 -0.034	1.000	
NTPCL	-0.099 -0.0998	0.123 0.122	-0.074 -0.074	0.026 0.025	-0.187 -0.188	1.000

The upper correlation in each cell is genotypic while the lower is phenotypic.

Significance Levels 0.05 0.01 0.001

If correlation r => 0.2072 0.2702 0.3411 for both phenotypic and genotypic, * P ≤ 0.05, ** P ≤ 0.01, ***P ≤ 0.001

Key: YLD – Yield, NTWT – Nut weight, NTPCL – Nuts per panicle, NTPT – Nuts per tree, KNWT – Kernel weight, %OT- Percentage out turn

Table 14: Correlations for yield and yield components of cashew hybrids at Chambezi site

	YLD	NTWT	NTPT	KNWT	%OT	NTPCL
YLD	1.000					
NTWT	0.0393 0.0391	1.000				
NTPT	0.9601*** 0.9602***	-0.099 -0.101	1.000			
KNWT	0.2058 0.2054	0.922*** 0.922***	0.075 0.073	1.000		
%OT	0.4705*** 0.4713***	0.583*** 0.581***	0.45*** 0.45***	0.771*** 0.770***	1.000	
NTPCL	0.1005 0.1002	0.229* 0.225*	0.123 0.124	0.248* 0.245*	0.346*** 0.346***	1.000

The upper correlation in each cell is genotypic while the lower are phenotypic.

Significance Levels	0.05	0.01	0.001 for genotypic	0.05	0.01	0.001 for phenotypic
If correlation r =>	0.2084	0.2717	0.343	0.2072	0.2702	0.3411

* $P \leq 0.05$, ** $P \leq 0.01$, ***$P \leq 0.001$

Key: YLD- Yield, NTWT – Nut weight, NTPCL – Nuts per panicle, NTPT – Nuts per tree, KNWT – Kernel weight, %OT- Percentage out turn

Table 15: Correlations for yield and yield components of cashew hybrids in combined analysis

	YLD	NTWT	NTPT	KNWT	%OT	NTPCL
YLD	1.000					
NTWT	0.0075 0.0075	1.000				
NTPT	0.9262*** 0.9257***	-0.226** -0.226**	1.000			
KNWT	0.1066 0.1057	0.926*** 0.926***	-0.113 -0.113	1.000		
%OT	0.4298*** 0.4293***	0.490*** 0.489***	0.414*** 0.414***	0.677*** 0.677***	1.000	
NTPCL	0.1938** 0.1935**	0.223** 0.223**	0.195** 0.195**	0.199** 0.198**	0.296*** 0.295***	1.000

The upper correlation in each cell is genotypic while the lower are phenotypic.

Significance Levels 0.05 0.01 0.001

If correlation r => 0.1463 0.1915 0.2433 for both phenotypic and genotypic. * P ≤ 0.05, ** P ≤ 0.01, ***P ≤ 0.001

Key: YLD- Yield, NTWT – Nut weight, NTPCL – Nuts per panicle, NTPT – Nuts per tree, KNWT – Kernel weight, %OT- Percentage out turn

4.8 Path Analysis

4.8.1 Associations among cashew yield influencing components at Nachingwea and Chambezi

4.8.1.1 Associations at Nachingwea

Results of associations among factors that influenced cashew yield at Nachingwea as described using path coefficient analysis are presented in Table 16, Fig. 2 and Appendix 3. Significant variability in causal relationships among cashew yield influencing components was observed. The highest genetic correlation on cashew yield was found on nuts per tree (r = 0.7883***) with the highest direct effect of nuts per tree (P =1.342) on cashew yield. Nuts per tree interacted negatively with nut weight (-0.4522) in influencing yield. The lowest genetic correlation (r = -0.099) was found between nuts per panicle and yield.

Table 16: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield at Nachingwea

Predictor variable	NTWT	NTPT	KNWT	%OT	NTPCL
NTWT	**0.629**	-0.4522	0.5579	-0.2893	0.0773
NTPT	-0.9648	**1.342**	-0.8199	0.5515	-0.0993
KNWT	0.1428	-0.0983	**0.161**	-0.0054	0.0041
%OT	0.0115	-0.0102	0.0008	**-0.025**	0.0046
NTPCL	-0.0103	0.0062	-0.0021	0.0157	**-0.084**
YLD	-0.1959	0.7883	-0.1056	0.2499	-0.099
Residual effects (Px6)					0.288

YLD=Yield, NTWT=Nut weight, NTPT=Nuts per tree, KNWT= Kernel weight, %OT= Percentage out turn, NTPCL = Nuts per panicle.

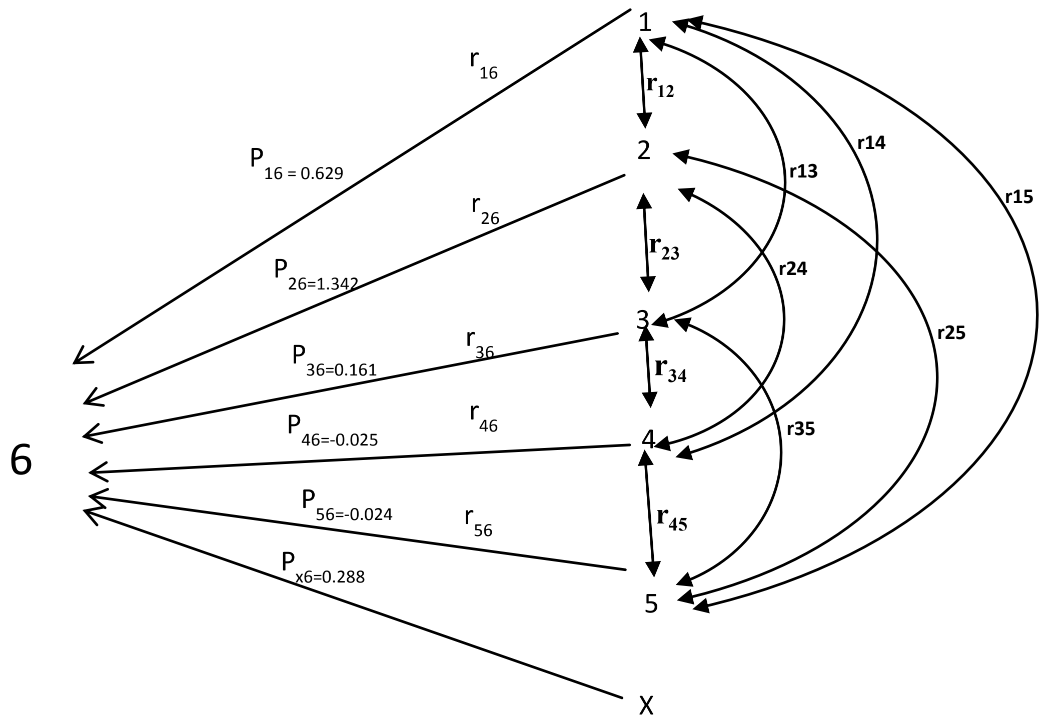

Figure 2: Path diagram showing relationships between yield and yield components of cashew at Nachingwea.

Where:

1 = Nut weight 2= Nuts per tree 3 = Kernel weight 4 = Percentage out turn, 5 = Nuts per panicle 6 = Yield X = Residual P = Direct effect and r = correlation coefficient.

P_{16} = effect of nut weight P_{26} = effect of nuts per tree
P_{36} = effect of kernel weight P_{46} = effect of percentage out turn P_{56} = effect of nuts per panicle P_{x6} = residual effect

r_{16} = -0.1959	r_{12} = -0.719	r_{24} = 0.411
r_{26} = 0.7883	r_{13} = 0.887	r_{25} = -0.074
r_{36} = - 0.1056	r_{14} = -0.460	r_{34} = -0.034
r_{46} = 0.2499	r_{15} = 0.123	r_{35} = 0.026
r_{56} = -0.099	r_{23} = -0.611	r_{45} = -0.187

The lowest direct effect was recorded on percentage out turn (P = - 0.025). The highest indirect effect on yield (-0.9648) was found with nut weight via nuts per tree. The lowest was found on variables which include: kernel weight via percentage out turn (0.0008), kernel weight via nuts per panicle (-0.0021), nuts per panicle via percentage out turn (0.0046), percentage out turn via kernel weight (-0.0054) and nuts per tree via nuts per panicle (0.0062).

Though the direct effect of nut weight was high and positive (0.629), it was compensated by the higher negative indirect effect via nuts per tree (-0.9648) to a low negative and non-significant correlation (r = -0.1959). With nuts per tree, the significant high and positive correlation (r = 0.7883) must have been predominantly due to the high direct effect of nuts per tree on yield (1.342). On kernel weight, the negative and non-significant correlation (r = -0.1056) must have been due to high positive indirect effect via nut weight (0.5579) compensating the highest negative indirect effect via nuts per tree (-0.8199). The percentage out turn interacted well with nuts per tree (0.5515) in the relationship with yield, resulting to a significant positive correlation (0.2499*) with yield.

4.8.1.2 Associations at Chambezi

Table 17, Fig. 3 and Appendix 4 present results of associations among factors that influenced cashew yield at Chambezi as described using path coefficient analysis. Significant variability in causal relationships among cashew yield influencing components was observed. The highest genetic correlation on cashew yield was found on nuts per tree (r = 0.9601***) with the highest direct effect on cashew yield recorded on nuts per tree (P =1.03). The lowest genetic correlation (r = 0.0392) was found between nut weight and yield. The highest indirect effect on yield (0.4635) was found on percentage out turn via nuts per tree. The lowest indirect effect was found on: nuts per tree via nuts per panicle (-0.0029), nut weight via nuts per panicle (-0.0054) and kernel weight via nuts per panicle (-0.0059).

The significant high and positive correlation (r = 0.9601***) of nuts per tree on yield was predominantly due to the highest direct effect of nuts per tree on yield (1.03). With respect to percentage out turn, significant high and positive correlation (r = 0.4705***) on yield was due to indirect effect of percentage out turn via nuts per tree (0.4635) and indirect effect of percentage out turn via kernel weight (0.2968).

Table 17: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield at Chambezi

Predictor variable	NTWT	NTPT	KNWT	%OT	NTPCL
NTWT	**-0.067**	0.0066	-0.0617	-0.039	-0.0153
NTPT	-0.1019	**1.03**	0.0772	0.4635	0.1266
KNWT	0.3549	0.0288	**0.385**	0.2968	0.0954
%OT	-0.1469	-0.1134	-0.1942	**-0.252**	-0.0871
NTPCL	-0.0054	-0.0029	-0.0059	-0.0083	**-0.024**
YLD	0.0392	0.9601	0.2058	0.4705	0.1005
Residual effects (Px6)					0.209

YLD= Yield, NTWT=Nut weight, NTPT=Nuts per tree, KNWT= Kernel weight, %OT= Percentage out turn, NTPCL = Nuts per panicle.

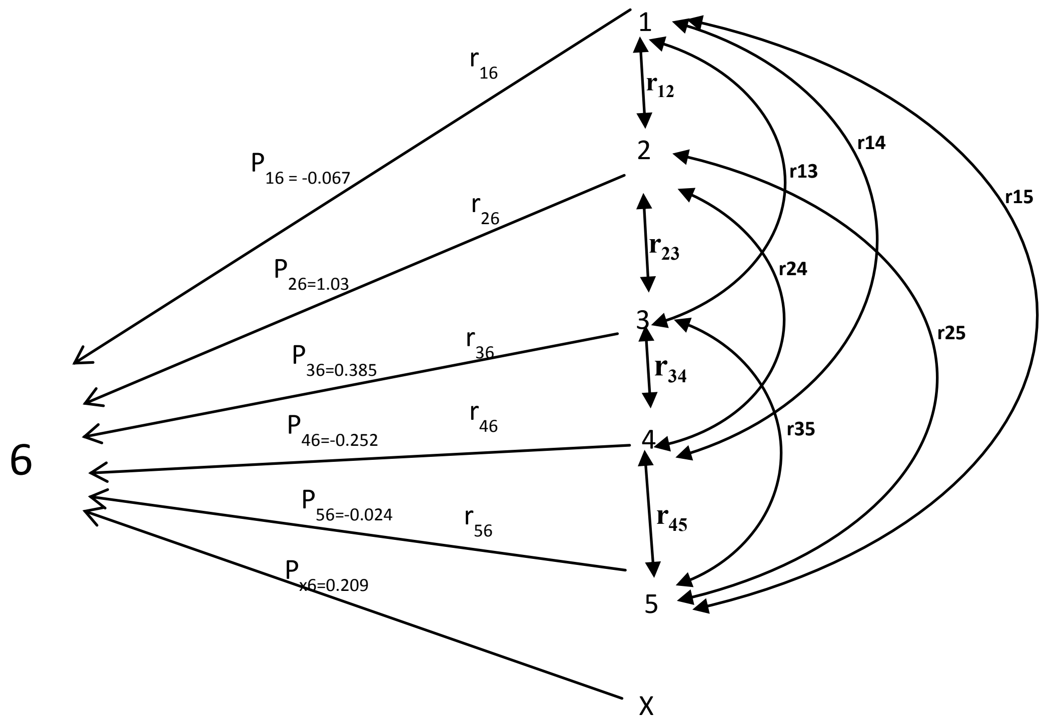

Figure 3: Path diagram showing relationships between yield and yield components of cashew at Chambezi.

Where:

1 = Nut weight 2= Nuts per tree 3 = Kernel weight 4 = Percentage out turn, 5 = Nuts per panicle 6 = Yield X = Residual P = Direct effect and r = correlation coefficient.

P_{16} = effect of nut weight P_{26} = effect of nuts per tree
P_{36} = effect of kernel weight P_{46} = effect of percentage out turn P_{56} = effect of nuts per panicle P_{x6} = residual effect

$r_{16} = 0.0392$	$r_{12} = -0.099$	$r_{24} = 0.450$
$r_{26} = 0.9601$	$r_{13} = 0.922$	$r_{25} = 0.123$
$r_{36} = 0.2058$	$r_{14} = 0.583$	$r_{34} = 0.771$
$r_{46} = 0.4705$	$r_{15} = 0.229$	$r_{35} = 0.248$
$r_{56} = 0.1005$	$r_{23} = 0.075$	r_{45}=0.346

4.8.1.3 Associations of cashew yield components in combined analysis

In combined analysis, nuts per tree were revealed to have the highest influence (1.133) on cashew yield (Table 18, Fig. 4 and Appendix 5). Also nuts per tree had the highest significant correlation coefficient (r = 0.9261***) with yield. The highest indirect effect on yield (0.4722) was found on nut weight via kernel weight. The lowest indirect effects were found on nuts per tree via nuts per panicle (-0.0027), kernel weight via nuts per panicle (-0.0027) and nut weight via nuts per panicle (-0.0031).

With respect to nut weight, the indirect effect via kernel weight (0.4722) compensated the high negative indirect effect via nuts per tree (-0.256) to a low positive and non-significant correlation (r = 0.0075).

The significant high and positive correlation (r = 0.9261***) of nuts per tree on yield was predominantly due to the highest direct effect of nuts per tree on yield (1.133).
The highest indirect effect of percentage out turn via nuts per tree (0.469) and percentage out turn via kernel weight (0.3452) contributed to the significant high and positive correlation of percentage out turn on yield (r = 0.4298***).

Significant and positive correlation of nuts per panicle on yield (r = 0.1937) was predominantly due to indirect effect of nuts per panicle via nuts per tree (0.2209).

Table 18: Path analysis of five selected variables showing direct (along Diagonal) and indirect effects on cashew yield in combined analysis

Predictor variable	NTWT	NTPT	KNWT	%OT	NTPCL
NTWT	**-0.026**	0.0058	-0.024	-0.0127	-0.0057
NTPT	-0.256	**1.133**	-0.128	0.469	0.2209
KNWT	0.4722	-0.0576	**0.51**	0.3452	0.1014
%OT	-0.1808	-0.1527	-0.2498	**-0.369**	-0.1092
NTPCL	-0.0031	-0.0027	-0.0027	-0.0041	**-0.014**
YLD	0.0075	0.9261	0.1065	0.4298	0.1937
Residual effects (Px6)					0.241

YLD= Yield, NTWT=Nut weight, NTPT=Nuts per tree, KNWT= Kernel weight, %OT= Percentage out turn, NTPCL = Nuts per panicle.

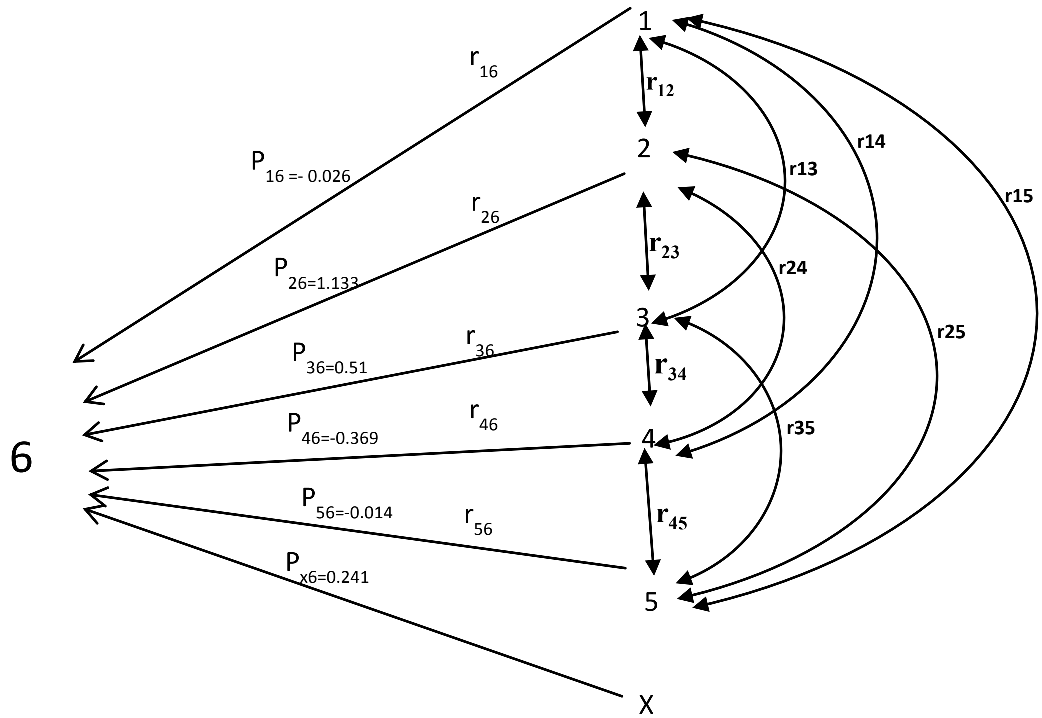

Figure 4: **Path diagram showing relationships between yield and yield components of cashew under combined analysis.**

Where:

1 = Nut weight 2= Nuts per tree 3 = Kernel weight 4 = Percentage out turn, 5 = Nuts per panicle 6 = Yield X = Residual P = Direct effect and r = correlation coefficient.
P_{16} = effect of nut weight P_{26} = effect of nuts per tree
P_{36} = effect of kernel weight P_{46} = effect of percentage out turn P_{56} = effect of nuts per panicle P_{x6} = residual effect

$r_{16} = 0.0075$	$r_{12} = -0.226$	$r_{24} = 0.414$
$r_{26} = 0.9261$	$r_{13} = 0.926$	$r_{25} = 0.195$
$r_{36} = 0.1065$	$r_{14} = 0.490$	$r_{34} = 0.677$
$r_{46} = 0.4298$	$r_{15} = 0.223$	$r_{35} = 0.199$
$r_{56} = 0.1937$	$r_{23} = -0.113$	$r_{45}=0.296$

4.9 Stability Analysis

Analysis was done using Wi-ecovalence from Agrobase statistical program. The observations from this study (Table 19) revealed that, there were variations in stability of the hybrid traits as most of them were stable in one or more traits but unstable in other traits. In Wi-ecovalence the agronomic trait is considered stable once the lowest Wi is recorded. The stability analysis on yield revealed that, nine hybrids were more stable across the locations as they recorded low Wi values. These were H3, H23, H22, H28, H6, H5, H12, H9 and H24. On the other hand hybrids H4, H14, H8, H17 and H11 were considered least stable as they had the highest Wi values.

With respect to nut weight, genotype H6, H8 and H16 appeared to be most stable due to their very low Wi (0.00) values. On this variable a number of hybrids were relatively stable as they had lowest Wi values.

With respect to nuts per tree hybrids H2, H27, H19, H1 and H5 had the least Wi values. Therefore, they are considered as the most stable genotypes in terms of nuts per tree. A number of hybrids on the other hand had high values of ecovalence, these included H23, H24, H15, H17, H26, H29, H8, H30, H7, H4 and H3 hence were considered unstable.

Table 19: Wricke's ecovalence (Wi) stability results of yield and yield components of cashew hybrids tested in two locations (Southern and Eastern Tanzania)

AGROBASE: GXE - Wi - Ecovalence

Genotype	YIELD GXE Statistic	Rank	NUTWT GXE Statistic	Rank	NTPCL GXE Statistic	Rank	NTPT GXE Statistic	Rank	KNWT GXE Statistic	Rank	OT% GXE Statistic	Rank
H1	6.665	14	0.58	22	0.101	13	2.199	4	0.017	15	2.447	23
H2	6.122	13	1.80	30	0.020	5	0.117	1	0.149	29	0.657	14
H3	0.031	1	0.38	21	1.185	24	182.462	20	0.020	17	2.004	20
H4	48.305	30	0.04	7	0.008	4	208.141	21	0.018	16	1.419	17
H5	1.064	6	0.26	18	0.378	19	9.693	5	0.005	10	2.420	22
H6	0.954	5	0.00	2	1.329	26	53.737	14	0.000	1	0.155	9
H7	6.841	15	0.13	13	1.329	27	208.427	22	0.020	18	0.671	15
H8	23.674	28	0.00	3	0.068	11	211.090	24	0.006	11	2.200	21
H9	2.955	8	0.01	4	0.720	20	23.715	9	0.002	5	0.009	3
H10	9.121	17	0.19	15	0.146	16	44.152	12	0.009	13	4.917	30
H11	19.914	26	0.05	9	0.001	1	59.046	15	0.050	23	0.813	16
H12	1.396	7	1.06	27	0.020	6	11.201	6	0.042	22	1.434	18
H13	5.059	12	0.29	19	0.146	17	91.166	19	0.000	3	2.981	25
H14	30.350	29	0.89	25	2.419	30	59.875	16	0.078	24	0.288	12
H15	13.881	22	0.23	16	1.621	28	284.006	28	0.002	6	3.821	27
H16	16.411	23	0.00	1	0.001	2	44.302	13	0.025	19	4.544	28
H17	22.452	27	0.34	20	1.621	29	277.136	27	0.004	8	2.479	24
H18	18.782	25	0.04	6	0.045	9	66.736	17	0.004	9	0.000	1
H19	12.797	21	0.25	17	0.001	3	1.830	3	0.032	20	0.576	13
AC4	8.816	16	0.95	26	0.106	14	38.518	11	0.151	30	0.229	10
H21	4.593	11	0.85	24	0.045	10	15.585	7	0.097	26	0.012	4
H22	0.491	3	0.08	11	0.020	7	34.304	10	0.011	14	0.143	8
H23	0.121	2	0.03	5	1.185	25	378.043	30	0.033	21	0.274	11
H24	3.331	9	0.13	12	0.068	12	337.039	29	0.000	2	4.554	29
H25	12.595	20	0.06	10	0.845	21	71.127	18	0.009	12	0.048	6
H26	9.640	18	0.75	23	0.106	15	214.804	26	0.085	25	0.036	5
H27	4.467	10	1.62	29	0.199	18	0.503	2	0.138	28	0.128	7
H28	0.479	4	0.17	14	0.020	8	17.129	8	0.003	7	3.519	26
H29	9.684	19	1.11	28	1.066	23	211.706	25	0.104	27	0.000	2
H30	18.295	24	0.05	8	0.938	22	208.631	23	0.000	4	1.607	19

Key: NUTWT=Nut weight, NTPCL=Nuts per panicle, NTPT=Nuts per tree, KNWT=Kernel weight, %OT=Percentage out turn

The results of stability for nuts per panicle showed a number of hybrids to be stable viz. H11, H16, H19, H4, H2, H12, H22, H28, H18, H21, H8, H24, H1, H26, H10, H13, H27, H5, H9, H25 and H30 as they had lowest ecovalence values. With respect to kernel weight, it was interesting to note that all hybrids could be considered stable as they had the least Wi values. Of these, hybrids H6, H13 H24 and H30 were the most stable.

Results from stability analysis for percentage outturn revealed that, fifteen genotypes namely H18, H29, H9, H21, H26, H25, H27, H22, H6, H23, H14, H19, H2, H7 and H11 showed adaptation to a wide range of environmental conditions as they had low ecovalence values. This suggests that, these genotypes were stable.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Performance of Cashew Hybrids in the Locations

Genotypes x Environmental interactions were significant for all the studied agronomic variables indicating differential genotypic responses of yield and yield components across environments. The six traits tested varied from location to location implying that selection for these traits has to be performed at each location.

5.1.1 Cashew yield

Results from this study showed variations on cashew yield among genotypes within and across locations. Yield for the hybrids ranged from 9.48kg/tree to 26.92kg/tree both at Chambezi. The range was higher than the one reported by Aliyu and Awopetu (2007a) of 7.82 to 14.04kg/tree for Nigeria cashew germplasm collections. Desai (2008) obtained yields of 0.25, 2.41, 8.65, 10.02 and 30.50kg/tree for some Tanzania cashew varieties. The wide margin in yield per tree is dependent on the genetic source of the materials (Aliyu, 2007). Eleven hybrids namely H3, H5, H6, H15, H16, H22, H23, H24, H26, H27, and H29 were identified as the best as they excelled across locations. Seven hybrids namely H2, H4, H7, H18, H19, H25 and H30 excelled at Nachingwea which imply that these hybrids were site specific thus favorable to Nachingwea. On the other hand six hybrids namely H1, H8, H10, H11, H13 and H17 appeared to be better at Chambezi site which imply that, these hybrids can be grown at this site.

The overall mean at Nachingwea was much higher as compared to Chambezi, with 19.59kg and 14.75kg, respectively. Probably the low performance at Chambezi may be attributed to the weather conditions that prevailed during the cropping season 2014/2015 (Appendix 2), which favored the development of cashew leaf and nut blight disease. The cashew leaf and nut blight disease incidence was much higher at Chambezi as compared to Nachingwea (Tables 4 and 5). These results agree with previous study by NARI (2012), which reported that, cashew leaf and nut blight disease develops under warm and humid conditions and is most active during wet weather especially after off season rains. Desai (2008) attributed differences in cashew yield to agro climatic conditions, age, inherent genetic makeup of the genotype or cultivar and the interaction of both with the environment.

On the other hand, the above hybrids were identified as superior yielding genotypes although they were not significantly different from the control AC4 but numerically high. AC4 is recognized as the high yielding cashew variety grown in Southern and Eastern Zones of Tanzania, and other parts of the country with similar ecological conditions at the elevation of 0 to 800 m above sea level (Masawe, 2006). Therefore these hybrids offer a possibility of releasing higher yielding genotypes performing better than the existing genotypes.

5.1.2 Nut weight

It was interesting to note that, all hybrids at Chambezi and Nachingwea with exception of H29 and H2 at Nachingwea had nut weights greater than the minimum recommended (6.5g) by cashew breeders in Tanzania. The mean nut weight ranged from 5.76g to 9.87g which differed a bit from the results of Blaikie *et al*. (2002) who reported a range of 5.3g to 10.9g. The nature of the materials and the location used could account for such slight differences. Chambezi had higher nut weight compared to Nachingwea. High nut weight at Chambezi probably was supported by the good moisture availability (Appendix 2), which might have favoured vegetative growth that increased surface area for photosynthetic activities and more photosynthetic products directed to seed formation. Chambezi site is a better site for nut weight compared to Nachingwea as a number of hybrids at Chambezi performed better than at Nachingwea.

5.1.3 Nuts per tree

Based on this study, it was observed that the mean of nuts per tree varied significantly within and across locations whereby Nachingwea had higher number of nuts compared to Chambezi. Number of nuts per tree for the hybrids ranged from 1084 at Chambezi to 4155 at Nachingwea. Probably the differences may have been caused by presence of leaf and nut blight diseases at Chambezi, as it recorded high disease incidence compared to Nachingwea which might have reduced the number of nuts after infection. It is also possible that reproductive efficiency of the hybrids was higher at Nachingwea compared to Chambezi, thus the potentiality of the hybrids were much favoured at Nachingwea. Results are higher than the one reported by dela Cruz and Fletcher (1997) of 151 to 1555 nuts. New-Leaf (2000) reported cashew trees to produce around 3000 nuts which are within the range obtained in this study. Genetic source of the materials and the location used could account for such differences. A number of hybrids outperformed the control variety AC4 within and across the locations. This is a good indication of obtaining superior genotypes with higher number of nuts than the existing varieties.

5.1.4 Nuts per panicle

The nuts per panicle results (overall mean 4.40) differ to some extent with those reported by Ohler (1979) of 4.8. The locations and genotypes used could account for the difference. Nachingwea had slight higher number of nuts per panicle as compared to Chambezi, probably this low performance at Chambezi might have been attributed to disease pressure. Also, the reproductive efficiency with location might have accounted for the difference.

5.1.5 Kernel weight

The mean kernel weight at Chambezi was a bit high compared to Nachingwea, this could have been contributed by the higher precipitations experienced during the season at Chambezi. The kernel weight which ranged from 1.71g at Nachingwea to 2.86g at Chambezi was lower than the maximum and higher than the minimum of the range reported by Blaikie *et al*. (2002) of 1.4 g to 3.2 g. As well as yield, economic value of cashew is determined by kernel characteristics. Commercial kernel size (weight) is influenced by nut size and kernel recovery, the latter being the proportion (%) by weight of the kernel in the whole nut.

5.1.6 Percentage out turn

The percentage out turn ranged between 24.50 and 31.87%. This differed a little bit from the results obtained by Blaikie *et al.* (2002) who reported the range between

26% and 34%. However, these results were higher than the minimum standard (20%) recommended by cashew processors in Tanzania (NARI, 2012). Thus, the accessions are within the accepted standards on this variable.

5.2 Nutritional Quality Characteristics of the Studied Cashew Hybrids

Significant variations ($P \leq 0.05$) among hybrids were observed for quality parameters studied but there were no genotypic differences on calcium and sodium as no significance on Locations or Locations x Genotype interaction was observed.

5.2.1 Percentage Protein

In this study, percentage protein content in genotypes ranged from 16.63 to 22.59% across the locations. This differed to some extent with results by Kapinga (2009) in Southern Tanzania, where the crude protein ranged between 16.2 to 18.7%, and also Ologunde *et al.* (2011) who reported protein in Nigerian cashew ranging from 23.42 –26.39%. Ohler (1979) reported 21% as average protein percentage in cashew nuts. Across the locations, hybrids H15, H16, H18, H12, H1, H14, H27 and H30 were identified as better hybrids in protein. On the other hand Chambezi outperformed Nachingwea in protein probably due to more evaporation at Nachingwea that promotes volatilization (the loss of Nitrogen to the atmosphere as the component of amino acid) as the soil dries for a longer time at the later. Nachingwea experienced a prolonged period of months without rainfall. Also the soil moisture content might have caused this difference. Moisture should fill 15-70% of soil pore space (UH, 2007) for maximum mineralization (release of ammonia to the soil for plant uptake).

5.2.2 Percentage Fat

Overall fat mean of 41.23% obtained in this study was within the range of the results from Ologunde, *et al.* (2011) who reported percentage fat content of between 40.15 and 42.03%. Omosuli *et al.* (2009) recorded the percentage content of 43.95%. The genotypes and the environment are the possible reasons for the difference observed in fat content. The fat contents were higher at Chambezi compared to those at Nachingwea, probably for reasons provided by Mustafa *et al.* (2015) using canola crop. Mustafa *et al*. (2015) found that areas receiving higher precipitation give considerably higher oil and protein than the low rainfall areas.

5.2.3 Potassium

Across the locations potassium content ranged from 0.46 to 0.66%, which conforms to the results recorded by Kapinga (2009) who reported potassium range of 0.44% to 0.77%. Chambezi had higher potassium content than Nachingwea probably this might have been caused by higher soil temperatures (Appendix 2) as warm temperatures quicken the release of potassium from K-bearing minerals. And so, mineral K and “fixed” K become available more quickly at higher temperatures (UH, 2007).

5.2.4 Magnesium

The magnesium content across the locations in genotypes ranged from 0.21 to 0.34%. The results agree with the study of Ologunde, *et al*. (2011) who obtained a range of between 0.20 and 0.39%. Low content of magnesium at Nachingwea might have been caused by the fact that magnesium availability is limited to soils that are acidic and Nachingwea had soil pH of 5.5. The higher magnesium content at Chambezi might have been due to inherent magnesium content in the soil. Magnesium becomes available when primary and secondary minerals containing magnesium dissolve or weather and rainfall is an agent of this process. After release magnesium is held by the cation exchange capacity and in the soil solution may precipitate into secondary minerals whereby it is taken up by plants (UH, 2007). Therefore presence of more rainfall at Chambezi compared to Nachingwea might have speeded the release of magnesium ions and taken up by plants.

5.2.5 Copper

In this study, copper content in genotypes varied significantly across locations with the overall mean of 17.26ppm which is a bit higher than the overall mean recorded by Kapinga (2009) which was 16.4ppm. Copper content ranged from 4.7ppm to 35.06ppm with H17, H29, H30 and H22 appearing to be more richer in copper content at both locations but also higher yielding hybrids. Therefore selection of these hybrids have an added advantage of being good in copper. On the other hand, Nachingwea was better in copper, this may have been caused by the fact that copper availability decreases as pH increases, primarily due to decreased solubility of copper minerals (UH, 2007). Chambezi had higher soil pH than Nachingwea (Appendix 1), which may have limited the availability of copper to plant roots leading to low content. Plants need copper so as to complete their life cycle-to produce viable seeds. Without copper there would be no photosynthesis because this nutrient is necessary for chlorophyll formation (Nutri-Facts, 2010).

5.2.6 Iron

Iron content for the hybrids ranged from 32.12 to 52.9ppm across the locations. H17, H11, H12, H30, H1, H23 and H18 outperformed the control variety in combined analysis implying the possibility of having hybrids with higher iron content than the existing varieties. Chambezi was leading on this variable with the highest overall mean of iron (44.98ppm) compared to 41.21ppm recorded at Nachingwea. Possible reasons might be the interactions with other nutrients as excessive amounts of other micronutrients, particularly copper can decrease iron availability (UH, 2007). Nachingwea had higher amount of copper that might have interacted with iron and therefore reduced their availability to plant roots for uptake. Another reason might be the good soil aeration supported by the bimodal type of rainfall at Chambezi as this improves iron availability for plant uptake (UH, 2007). Iron is involved in photosynthesis, respiration, chlorophyll formation, and many enzymatic reactions.

5.2.7 Zinc content

Zinc content ranged from 31.56 to 43.73ppm across the locations. So far, the zinc content recorded in this experiment outperformed the ones reported by Kapinga (2009), of 29.9 to 33.2ppm but was within the range recorded by Ologunde *et al.* (2011) of 34.00 to 42.00ppm. Genotypes H6, H25, H26, H29 and H24 were better than control variety AC4 in zinc content but also were among the hybrids that had good yield across locations which imply one selecting these hybrids will not only benefit from yield but also in zinc content. Nachingwea was better for zinc content probably due to the fact that zinc availability decreases as pH increases (UH, 2007).

Nachingwea had less soil pH than Chambezi. Zinc is involved in growth hormone production and seed development.

5.2.8 Vitamin C

The vitamin C content of the genotypes in this study ranged from 186.0 to 216.8mg/100mL. The overall means at Chambezi and Nachingwea were generally lower (199.57 and 198.25mg/100mL respectively) than those reported by Lowor and Agyente-Badu (2009) who reported vitamin C ranging between 206.2 to 268.6mg/100mL. The genotypes and locations used could be the possible reason accounting for such difference. Genotypes H24, H29, H19, H22 and H6 were better in vitamin C and also had higher yields which means selection of these hybrids for breeding programs is more worth as the selection on the basis of nutritive value alone is not enough. Vitamin C in plants functions in photosynthesis as an enzyme cofactor (including synthesis of ethylene, gibberellins and anthocyanins) and in control of cell growth (Smirnoff *et al.* 2000).

5.3 Cashew Leaf and nut Blight Disease Reactions

Hybrids H22, H30, H5, H17, H27 and H24 appeared to be partially resistant across the locations, which imply that they can be grown at any location. The Genotypes x Environmental Interaction for disease reaction was significant, implying that genotypes had differential responses on disease reactions. Chambezi had the highest disease incidence with the overall mean of 51.0% compared to 27.27% recorded at Nachingwea. The highest incidence at Chambezi was probably due to the location having much more rain, creating more humid condition that facilitate development of the disease. The blight in cashew is caused by *Cryptosporiopsis sp*, which appears to be one of the 'water loving pathogens' which may be quite severe soon after rainfall. This disease problem appears to be very prominent after the off-season rainfall, especially during cashew production phase. For cashew production season without off-season rainfall, one may not notice the problem on cashew. The control variety AC4 is known to be susceptible to cashew leaf and nut blight (Masawe, 2006). It was interesting to note that a number of genotypes were below the control variety in percentage disease incidence suggesting that there is possibility of obtaining genotypes which are intermediate to resistant against the disease, paving way for release.

5.4 Genetic Correlations

Genotypic correlations were generally higher compared to the corresponding phenotypic correlations suggesting that relationships were mainly due to genetic causes. From the combined analysis the significant positive genotypic correlations between nuts per tree and yield (r = 0.9262***) are in agreement with the report of Aliyu (2006) who pointed out that nuts per tree is highly positively and significantly correlated with yield. Thus nuts per tree could be used as primary components for improving yield. Furthermore, the positive and significant genetic correlations between percentage out turn and yield was as reported by Kapinga (2009). The correlation between nuts per panicle and yield (r = 0.1938**) agreed with the one reported by Aliyu (2006). Positive and non-significant genetic correlation was observed between nut weight and yield (r = 0.0075) which also conform to Aliyu (2006) observation in cashew accessions in Nigeria. The highly significant positive correlated traits with yield suggest that, improvement of yield can be achieved through selection of these highly correlated characters.

Positive and significant genetic correlations were also observed between nuts per tree and percentage out turn (r = 0.414***), percentage out turn and nuts per panicle (r = 0.296***) and between nuts per tree and nuts per panicle (r = 0.195**) in the combined analysis. These variables were correlated with yield and among themselves which implies improving these variables will improve yield as well with no adverse compensation effects. There were also positive and significantly correlated variables which can be improved together as they indirectly contributed to yield improvement. These included: nut weight and percentage out turn (r = 0.490***), kernel weight and percentage out turn (r = 0.677***) and nut weight and nuts per panicle(r = 0.223**). The implication of correlated variables is that they can be selected together in an improvement program.

Nut weight in this experiment had negative and significant correlation with nuts per tree. This agrees with the study by Aliyu (2006). The possible reason for the negative correlation between the variables could be intraplant competition for the same resources. As the number of nuts increased using the same resources manufactured by the plant become ought to be distributed to all nuts leading to nut weight decrease. Selection of one variable will select against the other.

A positive and highly significant correlation was observed between nut weight and kernel weight, a result which conforms to the study by Kapinga (2009).

Generally nuts per tree, percentage out turn and yield were consistently and positively correlated among themselves at genotypic and phenotypic levels at each location. Thus, nuts per tree and percentage out turn could be used in selection programs in all the ecologies to improve yield without adverse compensation effects.

5.5 Overall Associations among Cashew Yield and its Components

Selection progress may be enhanced or retarded by the nature of inter trait correlations. A positive relationship indicates that selection for improvement would result in concomitant increase in one or more of the other components. This type of relationship was recorded in most of the studied traits.

Correlation of nuts per tree with yield, nut weight versus kernel weight and nuts per tree versus percentage out turn were the correlations that were consistently positive and significantly high at each location and in combined analysis. At both locations, the significant high and positive correlations were predominantly due to high direct effects of nuts per tree on yield. Aliyu (2006) also recorded the highest correlation between nuts per tree with yield.

From both direct influence and genetic correlation, increasing nuts per tree could increase yield. For maximum yield to be reached, selection for this character (nuts per tree) is of great importance. This is because both the correlation with yield and direct effect were high. The negative indirect effect of nuts per tree via kernel weight, percentage out turn via nuts per panicle did not mask the direct influence of nuts per tree on yield.

The highest negative direct effect on yield was recorded on percentage out turn but the genetic correlation of percentage out turn on yield was sizeable and significantly positive that conform to Kapinga (2009) observation. The indirect effects played greater roles in net effect by counterbalancing the opposing influences making the overall correlation between percentage out turn and yield positive. Even though percentage out turn recorded the highest negative direct effect on yield the character could be considered in a selection program as it was observed to have positive and significant correlation with yield; thus regarded as primary component to be considered in improving cashew yield. This correlation was due to favourable interactions (indirect effects) between percentage out turn with nuts per tree and kernel weight in influencing yield indirectly.

5.6 Stability for Yield and Yield Components

Among the hybrids studied there were variations in stability in relation to yield and other quality attributes. Among the least stable hybrids in yield, H4, H8, H17, H11, H18 and H30 registered high yield with good agronomic and nutritional traits. On the other hand H28, H12 and H9 appeared to be stable but recorded low yields. Therefore crosses between these two groups will combine stability and yield in the same background hence considered in selection for yield.

It was interesting to note that H22, H5 and H24 appeared to be the best as they were stable, high yielding with good agronomic and nutritional attributes and tolerant to blight disease. Therefore these hybrids can be considered in selection of hybrids for yield.

Twenty four hybrids had low ecovalence thus can be considered as stable based on nut weight. This agrees with the study by Aliyu *et al*. (2014) who observed nut weight as the most stable trait in cashew. Hybrids with low ecovalence have smaller fluctuations across environments and therefore are stable. Nut weight had a weak positive and non-significant correlation with yield thus cannot be regarded as the primary component in improving yield.

A large number of hybrids appeared to be stable in terms of nuts per panicle. With other traits of interest under consideration, this offers a wide range of selecting hybrids for breeding programs.

Among the hybrids H2, H27, H19, H1 and H5 were stable in terms of nuts per tree. A large number of hybrids displayed the highest instability for nuts per tree which conform to Aliyu *et al.* (2014) observation. It should be noted that nuts per tree is positive and significantly correlated with yield suggesting that improvement of this trait could help in improving yield.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study showed the presence of G x E interactions among the 30 genotypes and their yield components. High yielding genotypes with broad adaptation and some with specific adaptation were identified. Of these H3, H5, H6, H15, H16, H22, H23, H24, H26, H27 and H29 were adapted to varying environments. In the contrary, high yielding unstable hybrids H4, H30, H19, H25, H7, H2 and H18 were more suitable for Nachingwea site while H1, H8, H10, H11, H13 and H17 were more favourable for Chambezi site. Comparing the hybrids and control variety AC4 in yield, H26 was found to outperform in yield, nuts per tree and zinc content while a number of hybrids were statistically similar although numerically superior, suggesting the possibility of obtaining superior genotypes than the currently grown varieties.

Among the growth characters and cashew yield, positive and significant correlations were observed. Nuts per tree contributed more when correlation coefficients were partitioned into direct and indirect effects. This character therefore, should serve as basis for selection in cashew improvement.

While improvement in cashew nut yield could be rapidly achieved through selection of the correlated characters, improvement on nuts and kernels quality would better be accomplished through hybridization.

The nutritional quality characteristics of the genotypes tested showed variability. Hybrid H1 appeared to be suitable for a number of variables such as protein, fat, potassium, copper, iron, zinc and vitamin C. Hybrids H2, H6, H17, H18 and H22 were the best in iron, zinc and vitamin C contents. These hybrids have an added advantage of having high nutritional quality, therefore can be earmarked for improving other genotypes with high yield but low quality attributes.

Hybrids H5, H6, H22 and H24 were observed to be very stable in yield, nut weight, nuts per panicle and kernel weight and at the same time they were high yielding genotypes. Selection of hybrids for breeding programs should consider these genotypes.

6.2 Recommendations

From the results, it is recommended to undertake hybridization in hybrids H29 and H26 for improvement of nut and kernel quality as these hybrids had high yield. Improvement of cashew nut yield could be rapidly achieved through selection of the correlated characters.

It is recommended to undertake intercrosses between the stable, low yielding and good quality attribute hybrids (H28, H12 and H9) and the good quality, unstable and high yielding hybrids (H4, H8, H17, H11, H18 and H30) so as to have cashew varieties with high yield, quality and stable.

It is recommended that hybrids H22, H5 and H24 be considered for release as they appeared to be the best in stability, yield with good agronomic and nutritional attributes as well as tolerance to blight disease. They outperformed the control variety in vitamin C and in stability attributes; in addition H22 and H24 outperformed the control in zinc and copper content.

For future G x E experiments, it is recommended to employ the aspect of seasons or years and more sites in order to partition genotype x environment variance further into genotype x location x year interaction.

It is also recommended to investigate the rest of nutritional qualities of cashew such as carbohydrates, fiber, ash, vitamin K, phosphorus, carotene, thiamin and riboflavin so as to have a complete nutritional information of the genotypes. This is of great importance as far as cashew processing and marketing are concerned.

REFERENCES

Adebisi, A. M. (2009). Stability Analysis of Seed Germination and Field Emergence Performance of Tropical Rain-fed Sesame Genotypes. *Report and Opinion* 1(5):1-8.

Adeigbe, O. O., Olasupo, F. O., Adewade, B. D. and Muyiwa, A. A. (2015). A review on cashew research and production in Nigeria in the last four decades. *Academic journal* 10(5):196-209.

Aliyu, O. M. (2006). Phenotypic Correlation and Path Coefficient Analysis of Nut Yield and Yield Components in Cashew (*Anacardium occidentale* L.). *Silvae Genetica* 55: 19-25.

Aliyu, O. M. (2007). Pollen-style compatibility in cashew (*Anacardium occidentale* L.). *Euphytica* 158: 249-260.

Aliyu, O. M. and Awopetu, J. A. (2007a). Multivariate Analysis of Cashew (*Anacardium occidentale* L.) Germplasm in Nigeria. *Silvae Genetica* 56: 3-4.

Aliyu, O. M. (2012). Genetic diversity of the Nigerian cashew germplasm, 163-184. In: Genetic Diversity in Plants, eds. MahmutÇalişkan. InTech Publisher, Croatia. 498pp.

Aliyu, O. M., Adeigbe, O. O. and Lawal, O. O. (2014). Phenotypic Stability Analysis of Yield Components in Cashew (*Anacardium occidentale* L.) Using Additive Main Effect and Multiplicative Interaction (AMMI) and GGE Biplot Analyses. *Plant Breeding and Biotechnology* 2(4): 354-369.

AOAC, (2000). Official Methods of Analysis. 17th Edn., Association of Official Analytical Chemistry, Arlington, Virginia, USA VA: 2000pp.

Azam-Ali, S. H. and Judge, E. C. (2001). Small-Scale Cashew Nut Processing. ITDG Schumacher Centre for Technology and Development Bourton on Dunsmore, Rugby, Warwickshire, UK. 70pp.

Baker, R. J. (1988). Tests for crossover G x E interactions. *Canadian journal of plant Science* 68: 405-410.

Bathia, V. K. (2007). Some aspects of stability of crop varieties. I.A.S.R.I Library Avenue, New Delhi-110012. 11pp.

Blaikie, S., O'Farrell, P., Warren, M., Wei, X., Scott, N., Sykes, S., Chacko, E. (2002). Assessment and Selection of New Cashew Hybrids. Environmentally friendly paper, Canprint. Publication number 01/177. 29pp.

Bondari, K. (1999). Statistical Analysis of Genotype x Environment Interaction in Agricultural Research. Experimental Statistics, Coastal Plain Station, University of Georgia, Tifton, GA 31793-0748. 6pp.

Cassman, K. G. (1999). Ecological intensification of cereal production system: Yield potential, soil quality and precision agriculture. *Proceedings of the National Academy of Sciences USA* 96(11): 5952-5959.

CBT, (2012). Investment Opportunities in Cashew nut Industry in Tanzania. [http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups] site visited on 2/08/2014.

Davis, K. (1999). *Cashew. Echo Technical Note*. North Fort Myers, Florida. 4pp.

dela-Cruz, F. S. and Fletcher, R. J. (1997). Identification of Superior Cashew Trees from a Seedling Population. *Philippines Journal of Crop Science* 22 (2):83-88.

Desai, A. R. (2008). Molecular diversity and phenotyping of selected cashew genotypes of Goa, and physiological response of cv. Goa-1 to *in situ* moisture conservation. Thesis submitted to the University of Agricultural Sciences, Dharwad in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Horticulture. 580pp.

Dewey, D. R. and Lu, K. H. (1959). A correlation and path coefficient analysis of component of crested wheatgrass seed production. *Agronomy Journal* 51: 515-518.

ECI Africa, (2003). Cashew nut sub-sector study final report, October 2003. Development Alternatives Inc - Private Enterprise Support Activities Project Tanzania.73pp.

Eberhart, S. A. and Russel, W. A. (1966). Stability Parameters for comparing varieties. *Crop Science Journal* 6: 36- 40.

FAO, (1998). Cashew nut nutritional aspects.[http://www.fao.org/docrep/ 3005/ac451e/ac451e0b.htm#bm] site visited on 27/02/2014.

FAO, (2004). Small scale cashew nut processing. [http:/ /www.fao. org/inpho_ archive/content/documents/vlibrary/ac306e/ac306e03.htm#Chapter%202 %20-%20Cashew%20production] site visited on 25/02/2014.

FAOSTAT, (2015). Food and Agriculture Organization Statistics. [http:// faostat3 .fao.org/home/E] site visited on 12/09/2015.

Goncalves, 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 Havea clones in Sao Paulo State, Brazil*. [http:www.scielo.br/scielo.php] site visited on 15/02/2014.

Hai, (2013). Cashew Nutrition Facts and Benefits. [cajuco.com/blog/cashew-nutrition-facts-and benefits/] site visited on 23/11/2015.

Kang, M. S. (1998). Using genotype by environment interaction for crop cultivar development. *Advanced Agronomy* 35: 199 – 240.

Kapinga, F. (2009). Genotypic-Environmental effects on nut picking duration, yield and quality of seven cashew clones in South-Eastern Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro Tanzania. 130pp.

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. 224pp.

Kasuga, L. J. F. (2010). Status of the Cashew Industry in Tanzania. In: *Proceedings of the Second International Cashew Conference*. (Edited by Masawe, P. A. L., Esegu, J. F. O., Kasuga, L. J. F., Mneney, E. E. and Mujuni, D.). Kampala, Uganda, 26-29 April 2010. CAB International, Wallingford, UK. 177-182.

Kjeldahl, J. (1883). A new method for the estimation of nitrogen in organic compounds. *Journal of Analytical Chemistry* 22: 366-382.

Lowor, S. T. and Agyente-Badu, C. K. (2009). Mineral and Proximate Composition of Cashew Apple (*Anarcadium occidentale* L.) Juice from Northern Savannah, Forest and Coastal Savannah Regions in Ghana. *American Journal of Food Technology* 4: 154-161.

MAFC, (2014). Recommended agronomic practices on selected cultivated crops. [www.agriculture.go.tz/publications/publications.htm] site visited on 23/11/2015.

Masawe, P. A. L., Cundall, E. P. and Caligari, P. D. S. (1996). Distribution of cashew flower sex-type between clones and sides of tree canopies in Tanzania. *Annals of Botany* 78: 553-558.

Masawe, P. A. L. (2006). *Tanzania Cashew Cultivars: Selected Clones*; Cashew Research Programme, Naliendele Agricultural Research Institute, Mtwara, Tanzania. 64pp.

Masawe, P. A. L (2009). Modern Agro-practices in Cashew. *Journal of Science, Technology and Management* 2: 9-16.

Masawe, P. A. L. and Kapinga F. A. (2010). Aspects of cashew hybridization by controlled hand pollination in Tanzania. In: *Proceedings of the Second International Cashew Conference*. (Edited by Masawe, P. A. L., Esegu, J. F. O., Kasuga, L. J. F., Mneney, E. E. and Mujuni, D.). Kampala, Uganda, 26-29 April 2010. CAB International, Wallingford, UK. 5-14.

Mustafa, H. S., Batool, N., Iqbal, Z., Hasan, E and Mahmood, T. (2015). Effect of Fruit Position and Variable Temperature on Chemical Composition of Seeds in Brassica, Cotton, Sunflower and Maize Crops. *Researcher* 7(11):51-67.

NARI, (2012). Annual Cashew Breeding Research Report for 2012/13. Ministry of Agriculture, Food Security and Cooperatives, Tanzania. 63pp.

NARI, (2014). Annual Cashew Breeding Research Report for 2014/15. Ministry of Agriculture, Food Security and Cooperatives, Tanzania. 66pp.

New Leaf, (2000). Nut Trees. [www.treeplantation.com/nut-trees.html] site visited on 04/02/2016.

Northwood, P. J. and Kayumbo, H. Y. (1970). Cashew Production in Tanzania. Word crops UK. 22(2): 88-91.

Nutri-Facts, (2010). Agronomic information on nutrients for crops. [fritind.com/nutri_facts.html] site visited on 04/02/2016.

Ohler, J. G. (1979). Cashew Communication 71. Department of Agricultural Research, Koninklijk Institnut voor de Tropen, Amsterdam, ISBN: 9068320742. 260pp.

Ologunde, M. O., Omosebi M. O., Ariyo, O., Olunlade, B. A. and Abolaji, R. A (2011). Preliminary nutritional evaluation of cashew nuts from different locations in Nigeria. *Continental Journal of Food Science and Technology* 5 (2): 32 – 36.

Omosuli, S. V., Ibrahim, T. A., Oloye, D., Agbaje, R. and Jude-Ojei, B. (2009). Proximate and mineral composition of Roasted and Deffatted Cashew nut (*Anacardium occidentale*) Flour. *Pakistan Journal of Nutrition* 8(10): 1649-1651.

PASS, (2013). Draft Investment Potential in Cashew Nut Industry. [www.pass.ac.tz/cashew.pdf] site visited on 29/08/2014.

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* 94: 454 – 455.

Smirnoff, N. and Wheeler, G. L. (2000). Ascorbic acid in plants:biosynthesis and function. *Critical Reviews in Biochemistry and Molecular Biology* 35(4): 291-314.

UH, (2007). Soil Nutrient Management for Maui County. [www.ctahr.hawaii.edu/mauisoil/] site visited on 15/12/2015.

Woodroof, J. G. (1979). Tree nuts, production and processing products. Vol. III; 2nd ed. AVI Publishing Company, Inc. Westport, Connecticut: 219 – 220.

Wricke, G. (1962). On a method of understanding the diversity in field research. *Journal of Plant Breeding* 47: 92-96.

Yan, W. and Hunt, L. A. (2002). Interpretation of Genotype x Environment Interaction for Winter Wheat Yield in Ontario [http://crop.scijournals.org/cgi/content/full/41/1/19] site visted on 12/01/2014.

APPENDICES

Appendix 1: Soil characteristics of the experimental soils at Nachingwea and Chambezi

	Nachingwea	Chambezi
Parameter		
Soil texture	Clay	Sand loamy
Soil pH	5.5	6.6

Appendix 2: Meteorological data

Month	Rainfall(mm)		Mean monthly temperature(°C)	
	Nachingwea	Chambezi	Nachingwea	Chambezi
Jan-14	179.6	0.2	26.52	29.33
Feb-14	275.9	107.7	25.92	28.75
Mar-14	227.2	228.2	25.7	28.33
Apr-14	173.9	254	25.32	27.7
May-14	61.4	405	23.78	26.46
Jun-14	0	19.4	23.08	26.51
Jul-14	0	44	22.78	26.09
Aug-14	0	37.6	23.81	26.08
Sep-14	0	71.4	24.4	25.73
Oct-14	12.3	54.2	26.49	27.14
Nov-14	2.3	254.8	27.76	27.34
Dec-14	110.7	253.9	27.74	27.98
Total	**1043.3**	**1730.2**	**25.27**	**27.28**

Appendix 3: Path coefficients for Nachingwea of cashew hybrids yield influencing variables

	Effect	Coefficients
1	**Nut weight on yield, r_{16}**	**-0.1959**
	Direct effect of nut weight, P_{16}	0.629
	Indirect effect via nuts per tree, $r_{12}P_{26}$	-0.9648
	Indirect effect via kernel weight, $r_{13}P_{36}$	0.1428
	Indirect effect via percentage outturn, $r_{14}P_{46}$	0.0115
	Indirect effect via nuts per panicle, $r_{15}P_{56}$	-0.0103
	Total	**-0.1959**
2	**Nuts per tree on yield, r_{26}**	**0.7883*****
	Direct effect of nuts per tree, P_{26}	1.342
	Indirect effect via nut weight, $r_{12}P_{16}$	-0.4522
	Indirect effect via kernel weight, $r_{23}P_{36}$	-0.0983
	Indirect effect via percentage outturn, $r_{24}P_{46}$	-0.0102
	Indirect effect via nuts per panicle, $r_{25}P_{56}$	0.0062
	Total	**0.7883**
3	**Kernel weight on yield, r_{36}**	**-0.1056**
	Direct effect of kernel weight, P_{36}	0.161
	Indirect effect via nut weight, $r_{13}P_{16}$	0.5579
	Indirect effect via nuts per tree, $r_{23}P_{26}$	-0.8199
	Indirect effect via percentage outturn, $r_{34}P_{46}$	0.0008
	Indirect effect via nuts per panicle, $r_{35}P_{56}$	-0.0021
	Total	**-0.1056**

4	**Percentage outturn on yield, r_{46}**	**0.2499***
	Direct effect of percentage outturn, P_{46}	-0.025
	Indirect effect via nut weight, $r_{14}P_{16}$	-0.2893
	Indirect effect via nuts per tree, $r_{24}P_{26}$	0.5515
	Indirect effect via kernel weight, $r_{34}P_{36}$	-0.0054
	Indirect effect via nuts per panicle, $r_{45}P_{56}$	0.0157
	Total	**0.2499**
5	**Nuts per panicle on yield, r_{56}**	**-0.099**
	Direct effect of nuts per panicle, P_{56}	-0.084
	Indirect effect via nut weight, $r_{15}P_{16}$	0.0773
	Indirect effect via nuts per tree, $r_{25}P_{26}$	-0.0993
	Indirect effect via kernel weight, $r_{35}P_{36}$	0.0041
	Indirect effect via percentage outturn, $r_{45}P_{46}$	0.0046
	Total	**-0.099**

Appendix 4: Path coefficients for Chambezi of cashew hybrids yield influencing variables

	Effect	Coefficients
1	**Nut weight on yield, r_{16}**	**0.0392**
	Direct effect of nut weight, P_{16}	-0.067
	Indirect effect via nuts per tree, $r_{12}P_{26}$	-0.1019
	Indirect effect via kernel weight, $r_{13}P_{36}$	0.3549
	Indirect effect via percentage outturn, $r_{14}P_{46}$	-0.1469
	Indirect effect via nuts per panicle, $r_{15}P_{56}$	-0.0054
	Total	**0.0392**
2	**Nuts per tree on yield, r_{26}**	**0.9601*****
	Direct effect of nuts per tree, P_{26}	1.03
	Indirect effect via nut weight, $r_{12}P_{16}$	0.0066
	Indirect effect via kernel weight, $r_{23}P_{36}$	0.0288
	Indirect effect via percentage outturn, $r_{24}P_{46}$	-0.1134
	Indirect effect via nuts per panicle, $r_{25}P_{56}$	-0.0029
	Total	**0.9601**
3	**Kernel weight on yield, r_{36}**	**0.2058**
	Direct effect of kernel weight, P_{36}	0.385
	Indirect effect via nut weight, $r_{13}P_{16}$	-0.0617
	Indirect effect via nuts per tree, $r_{23}P_{26}$	0.0772
	Indirect effect via percentage outturn, $r_{34}P_{46}$	-0.1942
	Indirect effect via nuts per panicle, $r_{35}P_{56}$	-0.0059
	Total	**0.2058**

4	**Percentage outturn on yield, r_{46}**	**0.4705*****
	Direct effect of percentage outturn, P_{46}	-0.252
	Indirect effect via nut weight, $r_{14}P_{16}$	-0.039
	Indirect effect via nuts per tree, $r_{24}P_{26}$	0.4635
	Indirect effect via kernel weight, $r_{34}P_{36}$	0.2968
	Indirect effect via nuts per panicle, $r_{45}P_{56}$	-0.0083
	Total	**0.4705**
5	**Nuts per panicle on yield, r_{56}**	**0.1005**
	Direct effect of nuts per panicle, P_{56}	-0.024
	Indirect effect via nut weight, $r_{15}P_{16}$	-0.0153
	Indirect effect via nuts per tree, $r_{25}P_{26}$	0.1266
	Indirect effect via kernel weight, $r_{35}P_{36}$	0.0954
	Indirect effect via percentage outturn, $r_{45}P_{46}$	-0.0871
	Total	**0.1005**

Appendix 5: Path coefficients for combined sites of cashew hybrids yield influencing variables

	Effect	Coefficients
1	**Nut weight on yield, r_{16}**	**0.0075**
	Direct effect of nut weight, P_{16}	-0.026
	Indirect effect via nuts per tree, $r_{12}P_{26}$	-0.256
	Indirect effect via kernel weight, $r_{13}P_{36}$	0.4722
	Indirect effect via percentage outturn, $r_{14}P_{46}$	-0.1808
	Indirect effect via nuts per panicle, $r_{15}P_{56}$	-0.0031
	Total	**0.0075**
2	**Nuts per tree on yield, r_{26}**	**0.9261*****
	Direct effect of nuts per tree, P_{26}	1.133
	Indirect effect via nut weight, $r_{12}P_{16}$	0.0058
	Indirect effect via kernel weight, $r_{23}P_{36}$	-0.0576
	Indirect effect via percentage outturn, $r_{24}P_{46}$	-0.1527
	Indirect effect via nuts per panicle, $r_{25}P_{56}$	-0.0027
	Total	**0.9261**
3	**Kernel weight on yield, r_{36}**	**0.1065**
	Direct effect of kernel weight, P_{36}	0.51
	Indirect effect via nut weight, $r_{13}P_{16}$	-0.024
	Indirect effect via nuts per tree, $r_{23}P_{26}$	-0.128
	Indirect effect via percentage outturn, $r_{34}P_{46}$	-0.2498
	Indirect effect via nuts per panicle, $r_{35}P_{56}$	-0.0027
	Total	**0.1065**

4	**Percentage outturn on yield, r_{46}**	**0.4298*** **
	Direct effect of percentage outturn, P_{46}	-0.369
	Indirect effect via nut weight, $r_{14}P_{16}$	-0.0127
	Indirect effect via nuts per tree, $r_{24}P_{26}$	0.469
	Indirect effect via kernel weight, $r_{34}P_{36}$	0.3452
	Indirect effect via nuts per panicle, $r_{45}P_{56}$	-0.0041
	Total	**0.4298**
5	**Nuts per panicle on yield, r_{56}**	**0.1937*** **
	Direct effect of nuts per panicle, P_{56}	-0.014
	Indirect effect via nut weight, $r_{15}P_{16}$	-0.0057
	Indirect effect via nuts per tree, $r_{25}P_{26}$	0.2209
	Indirect effect via kernel weight, $r_{35}P_{36}$	0.1014
	Indirect effect via percentage outturn, $r_{45}P_{46}$	-0.1092
	Total	**0.1937**