KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
KUMASI, GHANA
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF CROP AND SOIL SCIENCES

GENOTYPE BY ENVIRONMENT INTERACTION IN GROUNDNUT GENOTYPES FOR YIELD AND OTHER AGRONOMIC TRAITS IN TWO LOCATIONS IN GHANA

AMBROSE S. FORPOH

AUGUST, 2015

GENOTYPE BY ENVIRONMENT INTERACTION IN GROUNDNUT GENOTYPES FOR YIELD AND OTHER AGRONOMIC TRAITS IN TWO LOCATIONS IN GHANA

A Thesis Submitted to the Department of Crop and Soil Sciences,
Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, In
Partial Fulfillment of the Requirements for the Degree of

MASTER OF PHILOSOPHY
IN
AGRONOMY (PLANT BREEDING)

AMBROSE S. FORPOH
(BSc. Agronomy)

AUGUST, 2015

DECLARATION

I, Ambrose S. Forpoh, do hereby declare that this work is the result of my own original research towards an M.Phil degree in Agronomy (Plant Breeding) and that this thesis has neither in whole nor part been presented anywhere for a degree. All references cited in relation to other works, have been duly acknowledged.

AMBROSE S. FORPOH (20357568)	----------	----------
(STUDENT NAME & ID)	SIGNATURE	DATE

Certified by:

PROF. RICHARD AKROMAH	----------	----------
(PRINCIPAL SUPERVISOR)	SIGNATURE	DATE

DR. JAMES Y. ASIBUO	----------	----------
(CO-SUPERVISOR)	SIGNATURE	DATE

DR. ENOCK A. OSEKRE	----------	----------
(HEAD OF DEPARTMENT)	SIGNATURE	DATE

ABSTRACT

Groundnut productivity in Ghana is generally low when compared to yields obtained in developed countries. The low yields can be partly attributed to unstable rainfall patterns, pest and disease infestation, and the low yielding varieties cultivated by farmers. Over the past years, a number of improved disease resistant cultivars have been released to boost local production. These improved varieties are however late maturing, and as such adoption rate among small-holder farmers is very low. To address the problem, 39 improved hybrid lines were developed from crosses between three farmers' preferred early maturing but low yielding varieties and two improved varieties, which are high yielding and late maturing. The development of improved lines which are both high yielding and early maturing is considered the most viable solution. The objective of the study was to evaluate 49 groundnut genotypes for yield and stability performances and to identify high yielding early maturing genotypes with superior agronomic performances. Forty-nine groundnut genotypes (39 improved lines and 10 checks) were evaluated at two locations (Fumesua and Ejura), representing two agro-ecological zones of Ghana during the major and minor cropping seasons of 2014. The trial was laid out in Lattice Square (7x7) Design with three replications per location. Significant variations ($p<0.05$) were observed among genotypes and highly significant variations ($p<0.01$) between locations, and their interaction with genotypes for pod yield. The combined mean square analysis for pod yield revealed that location main effects accounted for 97.22% of the total variation; while genotypes and genotype by environment interaction accounted for 0.58% and 0.61% of the total variation, respectively. Positive correlations were observed between pod yield and the following traits: pod yield per plant, number of pods per plant, 100-pod weight, shelling percentage, number of seeds per pod, and number of branches

per plant. CRG-AP x AZ-14-13 emerged as the second highest performer across locations and the best genotype among the improved hybrid lines. The genotype is early maturing, a trait preferred by groundnut farmers in Ghana; and was also identified as the ideal genotype in terms of stability and yield performance. Overall, ten improved lines were selected based on both yield performance and early maturity, ranging from 89.0 to 92.0 days to maturity.

DEDICATION

This work is dedicated to my beloved and caring parents, Mr. George T. Forpoh, Sr. and Mrs. Eva K. Forpoh, for all their care and struggle in bringing me up to this level. I also dedicate this thesis to my dear fiancée Maciya W. Koffa.

ACKNOWLEDGEMENTS

I am very grateful to the Almighty God for his loving kindness and blessings for the successful completion of this program. I would like to extend special thanks and appreciation to my supervisor Prof. Richard Akromah, the Provost of the College of Agriculture and Renewable Natural Resources, KNUST, and Coordinator of the Alliance for a Green Revolution in Africa (AGRA) Sponsored M.Sc. Scholarship Program, KNUST, Kumasi, for his scholastic guidance and valuable criticisms. I would also like to extend heartfelt thanks and appreciation to my Co-Supervisor, Dr. James Y. Asibuo, Head, Legumes Improvement Program; Council for Scientific and Industrial Research-Crops Research Institute (CSIR-CRI) for his professional guidance and invaluable mentorship during the course of my study. I want to also express my sincere gratitude to Dr. (Mrs.) Adelaide Agyeman of the Biometry Unit, Crops Research Institute and Alexander Wireko Kena of the Department of Crop and Soil Sciences, KNUST, for their assistance in analyzing all of the data generated during the course of this study.

I am very grateful and wish to express my wholehearted indebtedness to the Alliance for a Green Revolution in Africa (AGRA) for awarding me a scholarship to undertake this training. I offer my deepest gratitude to the Administration of the University of Liberia for granting me a study leave to pursue my postgraduate studies. Special thanks to Mr. C. Morlee Mends-Cole, Chairperson, Department of Agriculture, University of Liberia for his professional coaching throughout my career path. I would like to sincerely acknowledge Emmanuel G. Vah, Jr., a friend and brother, for his endless support and encouragement. I extend special appreciation to my senior brothers, George T. Forpoh, Jr. and Moses Harryson for their support. I wish to express love and appreciation to my

fiancée Maciya W. Koffa for her care and patience. I am grateful to Ms. Morleeta Mends-Cole for her moral support. Finally, I wish to sincerely thank my dear friend, Maxwell Lamptey and the entire team of the CSIR-CRI Legumes Improvement Program for their technical assistance.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AEC	Average Environment Coordinate
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of Variance
ASL	Above Sea Level
CGIAR	Consultative Group on International Agricultural Research
CRG	Crops Research Groundnut
CRI	Crops Research Institute
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
DAP	Days After Planting
et al.	And others
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FRI	Food Research Institute
GEI	Genotype by Environment Interaction
GGE	Genotype main effects and Genotype by Environment Interaction
G x E	Genotype by Environment
G x L	Genotype by Location Interaction
G x Y	Genotype by Year Interaction
G x L x Y	Genotype by Location by Year Interactions
GRVD	Groundnut Rosette Virus Disease
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
LSD	Least Significant Difference
Kg/ha	Kilogram per hectare
KNUST	Kwame Nkrumah University of Science and Technology
MoFA	Ministry of Food and Agriculture, Ghana
MT	Metric tonnes
Mt/ha	Metric tonnes per hectare
NPK	Nitrogen, Phosphorus and Potassium
PC	Principal Component

PGRC	Plant Genetic Resource Centre
SARI	Savannah Agricultural Research Institute
SAS	Statistical Analysis System
SAT	Semi-arid tropics
SMK	Sound Mature Kernel
SVP	Singular Value Partitioning
UNESCO	United Nation Educational, Scientific and Cultural Organization
WAP	Weeks After Planting

CHAPTER ONE

1.0 INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a self-pollinating, annual herbaceous legume; belonging to the family *Leguminoceae* and sub-family *Papilionaceae* (De Waele and Swanevelder, 2001). *Arachis hypogaea* L. is the most widely cultivated species of the genus *Arachis*, probably originated in the region of south Bolivia or northern Argentina and was subsequently taken to Africa, Europe and Asia (Hammons, 1994).

Groundnut is the thirteenth most important food crop of the world. It is ranked as the second most important cultivated grain legume and the world's fourth most important source of edible oil and the third most important source of vegetable protein (Taru *et al.*, 2008; Shilman *et al*., 2011). It has a tremendous potential to mitigating protein nutrition deficiency in poverty-ridden regions of the world. Nutritionally, it contains 44-56% oil, 22-30% protein, 9.5-19% carbohydrates, and is a rich source of dietary fiber, minerals, and vitamins (Savage and Keenan, 1994). Every part of the groundnut plant is used in some ways: kernels for human consumption, branches and leaves as fodder for cattle, and nitrogen fixed from its root as nutrient for the soil. The total global production of groundnut was 40.4 million metric tons from 24.5 million hectare area and an average productivity of 1.6 metric t/ha in 2012 (FAOSTAT, 2013). Groundnut is extensively grown throughout the semi-arid tropics (SAT) of Asia, Africa and North and South America; with Asia and Africa accounting for 50% and 46% of the global area and 64% and 28% of the global production, respectively (FAOSTAT, 2011).

Ghana is one of the leading producers of groundnut in the world. In term of production volume of in-shell groundnut in 2012, the country ranked 12th (475,056 mt) in the world and 4th in Africa, behind Nigeria, Senegal and Cameroon (FAOSTAT, 2013). Groundnut is the most important legume crop grown in Ghana in terms of the total production and value (Tsibey *et al*., 2003). Groundnut is grown in all agro-ecological zones; but is grown mainly in the northern savanna zone, where the highest yield of 1.92 mt/ha has been recorded (MoFA, 2011). The 2010 agricultural production figures showed that the Northern and Upper West Regions account for about 80 percent of the nation's total groundnut production (MoFA, 2011).

Groundnut is a staple food for millions of Ghanaians and is cultivated for both commercial and subsistence ventures (Tsigbey *et al.*, 2003; MoFA, 2011). The crop provides an inexpensive source of high quality dietary protein and edible oil which has helped in reducing malnutrition in the country. Groundnut protein is fast becoming important as food and feed sources in Ghana, where protein from animal sources are not within the means of the majority of the populace. Groundnut is also processed into paste (butter) and widely used by Ghanaians to make soup, stews, and cereal mixtures (Asibuo *et al*., 2008*a*).

Groundnut production in Ghana increased from 420,000 mt in 2005 to 475,056 mt in 2012; with a reduction in the total area under cultivation from 450,000 ha in 2005 to 345,186 ha in 2012 (FAOSTAT, 2013). The same period also recorded a slight increase in average yields from about 840 kg/ha in 2005 to 1,200 kg/ha in 2012 (FAOSTAT,

2013). Despite the increase, average yields still remain low when compared to yields of 2,500 kg/ha obtained in developed countries (Nutsugah *et al*., 2007; FAOSTAT, 2014). The low yield of the groundnut crop can be partly attributed to a number of limiting factors including unstable rainfall patterns, pest and disease infestation, lack of quality seeds and inappropriate agronomic practices. The groundnut crop is also 100 percent inbred and as such cultivar improvement is quite challenging (Smith, 1954; Purseglove, 1975). Besides these, major limiting factors resulting to reduced yields can be attributed to environmental and genetic factors, and their interaction (Tsigbey *et al*., 2003).

It is therefore important to identify or develop cultivars for specific purposes through the understanding of the interaction of genotypes with predictable environmental factors (Yan and Hunt, 1998; Beyene *et al*., 2011). Results of such trials continue to provide important information on cultivar performance with regards to environment, genetic traits, or the interactions of both. The knowledge of a variety's performance in different agro-ecologies is necessary to select genotypes that are adapted to specific local conditions, as well as those that are stable across locations.

Genotype by environment (G x E) interaction refers to the changes in the relative performance of genotypes across different environments (Yau, 1995). The phenotype of an organism is determined by the combined effects of the environment and the genotype which interact with one another. Genotype by environment interaction (GEI) is of leading importance in expansion of improved genotypes by plant breeders. The stability of genotype for yield and agronomic performance is an urgent breeding objective (Bernardo, 2002).

According to Nigam *et al*. (1991), selection for yield has been the major basis for improving groundnut productivity in the world. An understanding of the physiology of yield is therefore essential to better target yield increase. In a study involving grain yield improvement in groundnut, Aminifar *et al.* (2013) reported that the most important yield contributing parameters were pod yield per plant, number of pods per plant, shelling outturn, and 100-seed weight. Squire *et al*. (1996) also stated that genotypes with desirable traits including earliness are major contributory factors to grain yield.

Hence, the overall objective of the study was to investigate the influence of genotype by environment (G x E) interaction on yield and other agronomic traits of groundnut genotypes across two locations in Ghana.

The specific objectives of the study included the following:

1. Evaluate forty-nine groundnut genotypes for yield performance parameters and agronomic traits across two locations and seasons in Ghana;
2. Assess the stability of yield performances of forty-nine groundnut genotypes across two locations in Ghana;
3. Identify high yielding early maturing groundnut genotypes for use by farmers in Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Origin and Distribution of Groundnut

Groundnut (*Arachis hypogaea* L.) is a self-pollinating, annual herbaceous legume; belonging to the family *Leguminoceae* and sub-family *Papilionaceae* (Tweneboah, 2000; De Waele and Swanevelder, 2001). *Arachis hypogaea* L. is the most widely cultivated species of the genus *Arachis* and is believed to have originated from South America probably in the region of south Bolivia or northern Argentina and was subsequently taken to Africa, Europe and Asia by the Portuguese and Spanish in the 16th Century (Hammons, 1994).

The three world largest producers of groundnuts are China, India and the U.S.A respectively, with annual production of 16.8, 4.7 and 3.1 million metric tons (FAOSTAT, 2013). In term of production volume of in-shell groundnut, Ghana ranked 12th (475,056 mt) in the world and 4th in Africa, behind Nigeria, Senegal and Cameroon (FAOSTAT, 2013).

In Ghana, groundnut is grown in all agro-ecological zones; however, about 80 percent of the nation's total production is grown in the Northern and Upper West Regions (MoFA, 2011). The northern savanna zone also recorded the highest yield of 1.92 mt/ha according to the 2010 agricultural production data (MoFA, 2011).

2.2 Botany and Morphology

Domesticated groundnut (*Arachis hypogaea* L.) is described as *Arachis* (from the Greek word arachus), meaning weed and *hypogaea* meaning underground chamber, referring to the formation of pods in the soil. Like the bambara groundnut of West Africa, all species of *Arachis* are geocarpic, forming their fruits underground (Tweneboah, 2000).

Groundnut is a self-pollinated legume with a central, upright stem and many lateral branches. According to classification done by Gregory *et al*. (1951), groundnut is divided into two large botanical groups. The two major types or botanical groups of cultivated groundnut are the *bunch* or *erect* types and the *runner* or *trailing* types. The bunch or erect type is designated as Valencia or Spanish groundnut; while the runner or trailing type is called the Virginia groundnut. The Virginia type consists of both the bunch and runner types (Chapman and Carter, 2000). The most important criteria used by Gregory *et al*. (1951) were the presence or absence of reproductive axes (inflorescence) on the main stem and the arrangement of reproductive and vegetative axes on the primary laterals. The Virginia type is characterized by the absence of reproductive axes on the main stem. It has an alternate branching pattern. The first two branches on the primary lateral are always vegetative. The Spanish or Valencia group is characterized by the presence of reproductive axes in a continuous series on successive nodes of lateral branches, on which the first branch is always reproductive. It has a sequential branching pattern. In addition, the Valencia or Spanish type is early maturing and the plant is generally erect and has pods clustered about the base of the plant while the seeds possess little fresh dormancy. The Virginia type, on the other hand, is late maturing and has pods dispersed along the

secondary and tertiary branches and the seeds possess appreciable fresh dormancy (Litzenberger, 1976).

The leaves are pinnate normally with two pairs of leaflets and are green or dark green in color. Darker leaves are found in Virginia groundnut, while Spanish and Valencia groundnut tend to have lighter leaves (Schilling and Gibbon, 2002). The flowers are sometimes white, but more often yellow to orange and are borne on inflorescence in the leaf axils. According to Chapman and Carter (2000), the flowers are sessile and are borne in leaf axils either singly or in groups up to three and are self-pollinated. Natural cross pollination occurs at the rates of less than 1% to greater than 6% (< 1% > 6%) due to atypical flowers and action of bees (Knauft *et al.*, 1987; Coffelt, 1989). After fertilization, the aerial flower grows downwards and enters the soil in a positive geotropic manner where the ovary at the tip of the peg grows into a pod containing the seeds (Tweneboah, 2000). Chapman and Carter (2000) indicated that the gynophore (a stalk-like structure) is commonly referred to as peg and the stage of the plant development at which the gynophore is activated and elongates is referred to as pegging. Tweneboah (2000) further described groundnut as an annual herb with a remarkable characteristic of producing fruits underground.

Groundnut plant has taproots with abundantly branched lateral roots on which globular, often dark brown nodules are usually present (Gregory and Gregory, 1986). Nodulation in groundnut is very essential in symbiotically fixing N_2 which can be made available to crops that succeed the groundnut. The ability to nodulate and fix N_2 is a genetic factor affected by environmental conditions (Dakora *et al*., 1987; Giller and Wilson, 1991).

2.3 Floral Biology of Groundnut

Groundnut is a self-pollinated crop with cleistogamous flowers, but natural outcrossing can occur to small extent where bee activity is high (Nigam *et al*., 1983). Flowering begins 17–35 days after seedling emergence depending on the cultivar and environmental conditions. Low temperatures generally delay flowering. The flowering pattern varies among and within botanical varieties. One or more flowers may be present at a node. Flower opening is normally at sunrise, but may be delayed by low temperatures (Bolhuis *et al*., 1965; Prasad *et al*., 1999). The stigma becomes receptive to pollen about 24 hours before anthesis and remains so for about 12 hours after anthesis (Hassan and Srivastava, 1966) and the dehiscence of anthers takes place 7 - 8 hours prior to opening of the flower in some varieties whereas in others they may not do so even at flower opening in the morning (Bolhuis *et al*., 1965). Fertilization occurs about 6 hours after pollination. Fertilization of the egg activates the growth and elongation of the intercalary meristem which is located at the base of the ovary. As a result, a stalk-like structure or 'peg' becomes visible within 4-6 days after fertilization under normal environmental conditions. Depending upon the prevailing temperatures, the peg or gynophore carrying the ovary and fertilized ovule on its tip appears in 6-10 days and grows to enter the soil (positively geotropic) where it develops into pods. The tip orients itself horizontally away from tap root (Nigam *et al*., 1990).

2.4 Economic Importance and Uses of Groundnut

Groundnut (*Arachis hypogaea* L.) is an important food crop and the fourth most important oil seed crop in the world in terms of production. It ranks third in the world in consumption and in export value (CGIAR, 2004-2005; FAO, 2008; Reddy and Bantilan,

2012). Groundnut is a staple food in a number of developing countries and is much valued for its protein content and as source of income for small holder farmers (Peanut CRSP, 1990). The crop is a good source of essential amino acids, healthy plant oils, and minerals such as P, Ca, Mg and K as well as vitamins like thiamine, riboflavin and niacin (Savage and Keenan, 1994; Schilling and Gibbon, 2002). The seeds contain 44-56% oil, 22-30% protein and 9.5-19% carbohydrates (Savage and Keenan, 1994). The seeds or kernels can be eaten raw, boiled or roasted, made into confectionery and snack foods, and are also used in soups or made into sauces (Marfo *et al*., 1999). Groundnut cake is suitable for animal consumption and the haulms are used as animal fodder; while the shells are used as fuel and fillers in fertilizer and feed industry (Reddy, 2009; Reddy *et al*., 2011). Other non-food uses of groundnut include soap making, cosmetics, medicines, lubricants and synthetic fiber (Raemekers, 2001; Reddy and Bantilan, 2011). As a nitrogen-fixing legume, groundnut enriches the soil through atmospheric nitrogen fixation (Reddy and Kaul, 1986).

In Ghana, the crop is an important oilseed and bulk of the production is used for extracting oil. Groundnut provides an inexpensive source of high quality dietary protein and edible oil which has helped in reducing malnutrition in the country. Groundnut protein is fast becoming important as food and feed sources in Ghana. The cake obtained after the extraction of oil is used in animal feed industry and in preparing enriched easily digestible food for children and aged persons, and as soil amendment (Asibuo *et al*., 2008*a*).

2.5 Climatic and Soil Requirements of Groundnut

Groundnut is a tropical plant and requires a long and warm growing season (Weiss, 2000). The favorable climate for groundnut is a well-distributed rainfall of at least 500mm during the growing season, and with abundance of sunshine and relatively warm temperature. The optimum temperatures for growing groundnuts range from 25°C to 35°C. Cooler temperatures, especially at night, can prolong the growing cycle. Schilling and Gibbon (2002) reported that germination is inhibited if temperature falls below 15^{o}C or rises above 45^{o}C. Groundnuts are slightly sensitive to photoperiod. Although the crop is drought tolerant, good performance is strongly linked to adequate soil water content at sowing time, followed by well-distributed rainfall. Early maturing small-seeded varieties require 300-500 mm while the medium to late maturing large-seeded varieties need 1000-1200 mm rainfall (Prasad *et al*., 1998; Ntare *et al*., 2008).

Rainfall is one of the most significant climatic factors affecting groundnut production in the semi-arid tropics (SAT), an ecological zone characterized by low and erratic rainfall. Low rainfall and prolonged dry spells during the growth periods have been reported to be the main reason for low average yields in most of the regions of Asia and Africa (Camberlin and Diop, 1999; Reddy *et al*., 2003). Nevertheless, groundnut is a drought tolerant crop and can withstand severe lack of water, but yield can be generally reduced (Brink and Belay, 2006). Moisture stress and adverse temperature have been observed to significantly reduce number of pods per plant (Sivakumar *et al*., 1993). Although groundnut is generally tolerant to drought, its sensitivity varies at different growth stages. The seed needs large amounts of water, close to the soils retention capacity, in order to germinate. In contrast, as soon as germination begins, the embryo has a high requirement

for oxygen. During the period up to flowering (0-30 days) the crop has good resistance to drought, but this is followed by a period of maximum sensitivity, during which there is considerable physiologically active flowering and pod formation. Relatively dry conditions are again favorable in the period to maturity. Rains at this stage can have a highly negative effect on yields especially in non-dormant types, which tend to germinate in wet soils or even while drying after harvest (Boote and Ketring, 1990; ICRISAT, 1992).

Groundnut grows best in well-drained sandy loam soils, as light soil helps in easy penetration of pegs and their development and their harvesting (De Waele and Swanevelder, 2001). The productivity of groundnut is higher in soils with pH between 6.0 - 6.5. Optimal shoot growth, nodulation and N_2 fixation are best at this pH range (6.0 - 6.5). The crop is highly sensitive to salinity and high soil acidity (pH<5) could induce magnesium or aluminum toxicity (Munns *et al*., 2002).

As a leguminous crop, groundnut can fix atmospheric nitrogen (N) with the aid of root bacteria (rhizobium). For this reason the crop is not dependent on nitrogen fertilization. Root nodules, which fix nitrogen effectively, have a pinkish appearance when dissected. Groundnuts with effective root bacteria do not need additional nitrogen. A reasonable level of organic matter must be maintained in the light, weakly structured, tropical soils where groundnuts are grown. Groundnut requires adequate levels of phosphorus, potassium, magnesium and particularly calcium, which are required for maximizing yield and good quality seed (Kipkoech *et al*., 2007). The nutritional requirement of groundnut is different as the pods develop in the soil. Calcium is an important nutrient required for

pod and kernel development. It is unique to groundnuts that the pods directly absorb most of the calcium, and therefore calcium fertilizers are applied in the pod zone at the peak flowering stage to ensure its availability to the pods (Nigam *et al*., 1990).

2.6 Cultivation and Management Practices

Good land preparation provides suitable soil conditions for rapid and uniform germination, good root penetration and growth, steady pod development and subsequently results to higher yield (Page *et al*., 2002; Schilling and Gibbon, 2002). It is appropriate to keep seeds in the shell until time of planting as viability declines rapidly after shelling and the testa is easily damaged (De Waele and Swanevelder, 2001). Adequate soil moisture is essential to guarantee good germination. However, excess soil moisture can trigger excessive vine growth (Wright *et al*., 2009). The period of greatest water use in groundnuts occurs during pegging and is necessary to move calcium through soil solution to pegs and developing pods.

Weed interference with groundnut is a major constraint to optimum production, requiring considerable investment of human labor to minimize negative impact on pod yield (Akubundu, 1987; Frimpong, 2002) as weeds compete with the crop for water, nutrients and light (De Waele and Swanevelder, 2001). In addition to weeds, groundnut is susceptible to a number of foliar and soil-borne diseases including early leaf spot (*Cercospora arachidicola*), late leaf spot (*Cercosporidium personatum*), rust (*Puccinia arachidis*) and the groundnut rosette virus disease (GRVD), transmitted by aphids (*Aphis craccivora*). These diseases can have a huge impact on yield and quality of groundnut seeds (De Waele and Swanevelder, 2001; Schilling and Gibbon, 2002).

It is very important to harvest groundnuts at the correct time. Groundnuts are mature when 70-80% of the inner shells have dark markings and the kernels are plump, with color characteristic of that variety. It is recommended that a few plants (3–5) be pulled up randomly and the pods shelled to examine the inner parts of the shells (De Waele and Swanevelder, 2001; Ntare *et al*., 2008). To ensure optimal shelf-life after harvest, the moisture content of the pods should be reduced to 6–8%, and this can normally be achieved by sun-drying the pods for 6-7 days (Mwariri *et al*., 2005).

2.7 Hybridization in Groundnuts

Artificial hybridization between parental lines to bring together a desirable combination of genes is an integral component of any crop improvement program (Nigam *et al*., 1990). Groundnut is a self-pollinated leguminous crop (normally with less than 1% cross-pollination), but cross-pollination up to a maximum of 10% has been reported (Knauft *et al*., 1987), resulting in natural hybridization. This outcrossing is related to the level of bee activity prevalent on a genotype in a season and at a specific location (Hammons, 1963; Gulp *et al*., 1968; ICRISAT, 1978). The success rate in artificial hybridization in groundnut depends largely on the proper understanding of the flower structure and its biology, adoption of an appropriate hybridization procedure, adequately trained personnel and a careful pollination control during and after the pollination stage. The choice of parents is the first and most important step in hybridization and depends on the breeding objectives. For hybridization in the field, rainy season is the best season as atmospheric humidity is high. Hybridization should be restricted to the early phase of flowering because of higher success rates in the production of mature pods from early-formed

flowers (Muhammad and Dorairaj, 1969; Bear and Bailey, 1973; Ramanatha Rao, 1988). Before beginning the hybridization process, it is very important to ensure that all the plants to be used are true-to-type and that only vigorous and healthy plants are selected. Acquaah (2007) recommended certain factors such as the crossing of unidentical but reproductively compatible parents and the parents should be obtained from the same species; the parents together should supply the critical genes needed to accomplish the breeding objective; one parent should be designated as female and the other male. The female parent needs some special preparation called emasculation (removal of the anthers before anthesis).

The conventional technique for hybridization in groundnut was described by Norden (1973) but some modifications have been described by Nigam *et al*. (1980). For convenience of operation, hybridization in groundnut is normally carried out on plants grown in pots or boxes. These pots are placed on tables inside a greenhouse or outside. Equipment required for hybridization includes forceps with fine points, colored nylon threads, petri dishes, and alcohol for rinsing forceps between pollinations. Emasculation, which is the removal of anthers from flower buds before their dehiscence to avoid self-pollination, should be carried out in the afternoon or evening depending on location and environmental conditions. Once a well-developed flower bud on a sufficiently elongated hypanthium is selected, all other buds at that node (axil of the leaf) should be removed with forceps. Removal of these buds ensures that only one flower is allowed to set a peg at each node and this facilitates the identification of hybrid pods. The bud is held gently between the thumb and index finger. Using a forcep, the single sepal opposite the standard petal is pulled down. The fused sepal is also folded down and held back. The

standard is then gently and carefully opened with a forcep and is held back by the thumb and index finger. The wing petals are pulled down locking them with the standard. The keel is pulled outwards by its ridge with a forcep to expose the anthers. All the anthers are removed with the filaments from their bases. This leaves only the stigma and style well exposed for pollination. The standard, wing, and keel petals should be carefully folded back to cover the style and stigma to prevent desiccation of the style. Damage to the style and stigma during emasculation makes the bud unfit for pollination. The internode just above the emasculated bud is then marked with a date-coded colored nylon thread. A thread of a different color is used every day to help identify the buds for pollination the next day. Pollination is carried out the day after emasculation as soon as buds start opening in the early hours of the morning (06:00 hrs), and should not exceed 09:00 hrs as atmospheric humidity, stigma receptivity, and pollen viability are high during this period (Norden, 1980; Sastri and Moss, 1982).

Pollination soon after buds open is best to achieve a high success rate. Before pollination is effected, the emasculated flower should be checked for the condition of the style. The flower should be pollinated if the style is fresh and of normal length. For pollination, a healthy flower from a pre-identified male parent plant is removed by breaking the hypanthium. The calyx, standard, and wing petals are detached for ease in operation. The keel petal is gently pressed between the thumb and index finger to squeeze the sticky pollen mass out from the anthers. The sticky lump of pollen is deposited on the tip of the stigma of the emasculated flower. It is possible to pollinate up to fifteen female flowers with one male flower, depending on the environmental conditions at the time of pollination. The pollinated flower should not be disturbed for some time after pollination

to avoid dislodging the pollen from the stigma. The forcep and fingers of the operator should be rinsed with alcohol when changing from one male parent to another to avoid contamination with unwanted pollen. All flowers except those that are artificially pollinated should be removed every day soon after pollination from the base of the hypanthium, to help prolong the duration of flowering of the female parent plant. This flower-removal operation should be carried on for at least two weeks after completing the last pollination of the season. This reduces competition for the development of hybrid pods. If the operation is successful, a peg will be seen emerging from the axil of the leaf just below the colored thread 4-6 days after fertilization. Routine checking of the developing hybrid peg should be carried out and if new buds or flowers are found, they should be removed. If a peg is not observed up to 2-3 weeks after pollination, the pollination is considered unsuccessful.

2.8 Correlations of Traits in Groundnuts

Correlation is a measure of the degree of association between traits. This association may be on the basis of genetics or may be non-genetic. Correlation analysis is a technique which helps to explain the degree of relationship among quantitative traits of a given genotype (Malik *et al.*, 2005). Correlation analysis also provides the information of interrelationship of important plant characters and hence, leads to a directional model for direct and indirect improvement in grain yield (Khan *et al*., 2004). In terms of response to selection, genetic correlation is what is useful. When it exists, selection for one trait will cause a corresponding change in other traits that are correlated (Acquaah, 2007). An understanding of the direction and extent of association of the component characters with economic yield is an essential pre-requisite for formulating best selection strategy in

breeding program. Selection for yield and other quality traits (oil content, protein, diseases and pests resistance) has been the major basis for improving groundnut productivity in the world (Nigam *et al*., 1991). Therefore understanding the physiology of yield is also essential to better target yield increase. Yield is a complex character governed by a large number of cumulative duplicate, non-dominant genes and is quantitatively inherited (Dorairaj, 1962). The important yield contributing parameters are: pod yield per plant, number of pods per plant, shelling outturn, and 100-seed weight. Lonnquist (1967) reported that quantitative traits are significantly affected by the environment.

Kotzamanidis *et al*. (2006) noted that correlation between the most important traits showed that the most significant correlation was found between 100-seed weight and 100-pod weight in total plants (0.86) and in cross type virginia x Spanish (0.89). Narasimhulu *et al*. (2012) revealed that pod yield per plant had significant positive association with kernel yield per plant, shelling percentage and sound mature kernel (SMK) percent. Pod yield show positive correlation with number and mass of seed plant^{-1} (Phadnis *et al*., 1973), 100 seed mass (Deshmukh *et al*., 1986), number of mature pods plant^{-1} (Alam *et al*., 1985; Liao *et al*., 1989). Abraham (1990) reported significant positive correlation of kernel yield with pods per plant, kernels per plant, 100-kernel weight and shelling per cent in a study involving 42 bunch type groundnut varieties. Reddi *et al*. (1991) reported a strong and positive correlation of pod yield with kernel yield, sound mature kernels and 100-kernel weight. Shah *et al*. (1993) reported that yield was positively correlated with pods per plant and seeds per pod.

Correlation studies on 18 varieties of groundnut indicated significant and positive correlation of pod yield with pods per plant, shelling per cent, kernel weight and harvest index (Sharma and Varshney, 1995). In a study involving 35 groundnut genotypes, a strong positive correlation of pod yield and 100-kernel weight but weak negative association with shelling per cent was reported (Vasanthi *et al*., 1998). A study involving 15 Valencia groundnut genotypes showed significant positive association of pod yield and kernel yield with kernels per plant and 100-kernel weight (Kavani *et al*., 2004). Chiow and Wynne (1983) reported that fruit size was highly correlated with seed weight and both were significantly correlated with yield suggesting that selection for large fruit would result in higher yield. The knowledge of existing variability and degree of association between yield contributing characters and their relative contribution in yield is essential for developing high yielding genotypes in groundnut (Patel *et al.,* 2009).

2.9 Groundnut Improvement and Release in Ghana

Groundnut is the leading cultivated grain legume in Ghana and is grown in all the agro-ecologies, from the dry savannah regions to the moist forest areas and the coastal savannah zone along the coast. However, limited hybridization work has been carried out to develop and release high yielding varieties compare to other food crops such as maize, cassava, and rice. The Council for Scientific and Industrial Research (CSIR)-Crops Research Institute (CRI) [based in Kumasi, Southern Ghana] and the Savanna Agricultural Research Institute (SARI) [based in Tamale, Northern Ghana] have conducted a number of research on groundnut improvement over the past decades and have subsequently released some improved groundnut varieties in the country. For example, Mani-Pintar, Shitaochi (Chinese), F-mix and Sinkarzei were released in 1960,

1970, 1985, and 1988, respectively (Atuahene-Amankwa *et al*., 1990; Ibrahim *et al*., 2012). Following the devastating effects of the rosette virus in 1993, forty groundnut accessions were received from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and evaluated at the CSIR-Crops Research Institute for resistance to the rosette virus. This study eventually led to the release of four improved varieties of groundnut in 2006 which were both high yielding and rosette virus resistant. The released varieties included Adepa, Nkosour, Jenkaah, and Azivivi. In addition, two Confectionery varieties (Oboshie and Obolo) were released in 2012 by CSIR-Crops Research Institute (CRI).

With an ever-increasing consumers' preference for high quality edible oils in Ghana and the desire to increase groundnut export on the world market, a study was carried out to investigate the nutritional quality of twenty groundnut varieties grown in Ghana (Asibuo *et al*., 2008*a*). Other studies carried out over the past years by the Crops Research Institute (CRI) include the study of the inheritance of fresh seed dormancy in groundnut (Asibuo *et al*., 2008*b*), chemical composition of groundnut (Asibuo *et al*., 2008*c*), among others.

Tremendous research work on groundnut improvement is on-going at the CSIR-Crops Research Institute in collaboration with other partners including the Ministry of Food and Agriculture (MoFA), Savanna Agricultural Research Institute (SARI), Food Research Institute (FRI), Plant Genetic Resources Research Institute (PGRRI) and the Universities as well as other international partners including the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Alliance for a Green Revolution in Africa

(AGRA), among others. This study, which seeks to investigate the influence of Genotype by Environment (G x E) interaction on yield and other agronomic traits in groundnut genotypes, is therefore an integral part of the ongoing groundnut breeding work at CRI. Findings from the study will provide information on stability of yield performance among groundnut genotypes as well as identifying and recommending high yielding early maturing groundnut cultivars for use by farmers in Ghana.

2.10 Genotype by Environment Interaction (GEI)

Genotype by environment (G x E) interaction refers to the changes in the relative performance of genotypes across different environments; or simply the differential ranking of genotypes among locations or years (Yau, 1995). Genotype describes the complete set of genes that is inherited by an individual and is important for the expression of specific traits (Suzuki *et al*., 1981). The observable uniqueness ensuing from the interaction between the genetic make-up and the environment are known as the phenotype. Phenotypes can therefore be observed, assessed, estimated, and arranged in groups according to features that they have in common. Environmental features such as locations, growing seasons, years, rainfall pattern, temperatures, soil pH, and biotic stresses such as diseases, insect pests and weeds could have positive or negative effects on genotypes (Falconer and Mackay, 1996; Banziger *et al*., 2004). Genotype x environment interaction (GEI) makes it difficult to select the best performing and most stable genotypes. Beyene *et al*. (2011) and Bernardo (2002) indicated that it is the rule in most quantitative characteristics. G x E interactions are therefore of leading importance in expansion of improved genotypes by plant breeders since they cause technical hitches in selecting genotypes evaluated in diverse environments (Kang and Gorman, 1989).

Very often breeders encounter situations where the relative rankings of varieties change from location to location and/or from year to year. When varieties are grown at several locations for testing their performance, their relative rankings usually do not remain the same. This causes difficulty in demonstrating significant superiority of any variety (Smith *et al*., 2005). The stability of genotype for yield and agronomic performance is an urgent breeding objective. Therefore, an understanding of the environmental stability of genotypes helps in determination of their stability for the fluctuations in growing conditions that are likely to be encountered. Plant breeders evaluate their germplasm in multi-environment to study the performance and adaptation for specific or general environment (Yan and Hunt, 1998). It is therefore important to identify or develop cultivars for specific purposes through the understanding of the interaction of genotypes with predictable environmental factors.

In addition, an understanding of environmental and genotypic causes of GEI is important at all stages of plant breeding, including parent selection based on specific traits, and selection based on yield. Knowledge of GEI can also be used to establish breeding objectives and to formulate recommendations for areas of optimal cultivar adaptation (Kang, 1996; Jackson *et al.*, 1998).

2.10.1 Classification of Genotype by Environment Interaction

Every factor that is part of the environment of a plant has the potential to cause differential performance that is associated with genotype x environment interaction (Peipho and Mohring, 2005). Environmental variables can be classified as either predictable or unpredictable factors. Predictable factors are those that occur in a

systematic manner or are under human control, such as soil type, planting date, row spacing, plant population and rates of nutrient application. Unpredictable factors, on the other hand, are those that fluctuate inconsistently, including rainfall, temperature and relative humidity (Kang *et al*., 2004; Crossa, 2012). Predictable factors can be evaluated individually and collectively for their interactions with genotypes. For example, genotype x soil type; genotype x row spacing; genotype x planting date; and genotype x plant population interactions can be evaluated individually and collectively. Unpredictable factors contribute to the interactions of genotypes with locations and years. Some interactions of unpredictable factors include genotype x location (G x L), genotype x year (G x Y), and genotype x location x year (G x L x Y) interactions. The relative performance of genotypes across environments determines the importance of an interaction. The most important G x E interaction which is of interest to a plant breeder is one caused by changes in rank among genotypes.

Genotype by environment interaction (GEI) can also be classified according to the behavior of the genotypes, i.e. either stable or adapted to a particular environment in terms of their yield or in some other interesting agronomic features. Generally, the term stability refers to the ability of the genotypes to be consistent, both with high or low yield levels in various environments. Adaptability, on the other hand, refers to the adjustment of an organism to its environment, e.g., a genotype that produces high yields in specific environmental conditions and poor yields in another environment (Balzarini *et al*., 2005). The response of genotypes to variable productivity levels among environments provides an understanding of their stability of performance.

2.10.2 Significance of Genotype by Environment Interaction

Genotype by environment interaction (GEI) is a phenomenon that is of significance to plant breeders, agronomists and farmers. Breeding materials can be selected and assessed on the basis of their different responses to the environments. Deitos *et al*. (2006) indicated that genotype by environment interaction is important for plant breeding because it affects the genetic gain and recommendation and selection of cultivars with wide adaptability. On the other hand, different genotypes may have different performance in each region that can be exploited to maximize productivity (Souza *et al*., 2008). Grain yield is one of the most important traits to consider when the performance of cultivars is compared across environments (Vargas *et al*., 1999). However, selection based on yield only may not always be adequate when genotype by environment interaction is significant (Kang *et al*., 1991). Linnemann *et al*. (1995) reported that it is important to understand crop development in relation to biophysical conditions and changes in season when selecting well-adapted genotypes and correct planting date. Varieties that show low genotype by environment interaction but have high and stable yields are desirable for plant breeders and farmers, because it indicates that the environment has less effect on them and their higher yields are largely due to their genetic composition. Knauft and Wynne (1995) reported significant genotype by environment interactions on yield and other agronomic traits in groundnut cultivars.

2.10.3 Yield Stability

The term stability refers to the ability of a cultivar to perform consistently across a broad range of locations, be it at high or low (Zivanovic *et al*., 2004; Kandus *et al*., 2010). Stability measurements gives an indication of the ability of a genotype to maintain a

relatively constant yield independent of changing environmental conditions (Odewale *et al*., 2012). According to Becker and Leon (1988), stable genotypes will not change in performance in spite of differences in the prevailing environmental conditions. It allows researchers to identify broadly adapted cultivars for use in breeding programs and have assisted in advancing suggestions to farmers (Yayeh and Bosland, 2000). A genotype is considered stable if its environment variance is small. Stability analysis provides a general solution for the response of the genotypes to environmental change.

Issa (2009) also described two basic concepts of phenotypic stability namely, the biological concept and dynamic concept. He related the biological concept of stability to the constant performance of a genotype over a wide range of environments and the dynamic stability, also known as agronomical concept of stability, implies that a stable genotype should always give high yield at the level of productivity of the respective environments. In Biological stability, the performance of a genotype will not change regardless of changes in environmental conditions, thus implying that differences among environments is zero and that stable genotype should show minimal variance in different environments (Becker and Leon, 1988; Dabholkar, 1999).

2.10.4 Adaptations of Genotypes

Adaptability of a given cultivar or genotype is defined as the inherent genetic ability of a cultivar to be stable or high yielding in various environments (Zivanovic *et al*., 2004). Almost all living organisms are capable of adjusting to the normal functions of their environment, which enable them to cope with conditions within their surroundings. Moreover, adaptability refers to the manner in which an organism adjusts to its

environment. For example, certain genotypes may produce high yields under certain environmental conditions but poor or low yields in other conditions (Balzarini *et al*., 2005). Adaptation of a cultivar is affected by factors that vary from one location to another and from year to year. The effects of these factors are usually reflected in their yields (Patterson *et al*., 1983; Zivanovic *et al*., 2004). In other words, under a particular set of environmental conditions, individuals (genotypes) with better adaptation will produce more yield than those that are less adaptable. The adaptability of a cultivar over diverse environments is usually tested by its degree of interaction with different growing environments.

The concepts of general and specific adaptations, proposed by Simmonds (1962) are often used to describe the relative performance of genotypes when adaptation is evaluated in more than one environment. General adaptation describes the response of a genotype where superior performance is expressed across a wide range of environments. Specific adaptation, on the other hand, describes a response where a higher level of performance is expressed in specific environments (Ramagosa *et al*., 1993). Specific adaptation is often associated with the occurrence of genotype by environment interaction (Ceccarelli, 1989).

2.10.5 GGE Bi-plot

Genotype main effect and genotype by environment interaction (GGE) bi-plot is a data visualization instrument that uses diagrams or graphs to illustrate G x E interaction in a two-way chart (Yan *et al*., 2000). It is a valuable instrument used for the evaluation of mega-environment for instance "which won- where" pattern, through which particular genotypes can be proposed for particular mega-environments (Yan and Kang, 2003).

GGE bi-plot can also be used for the evaluation of genotype mean performance and stability as well as for the evaluation of environment to differentiate between genotypes in target environments. GGE bi-plot analysis is more frequently used in G x E interaction studies in plant breeding research (Yan, 2001; Yan and Kang, 2003; Butron *et al.*, 2004).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Experimental Sites

The study was conducted in two locations in southern Ghana, namely; Fumesua and Ejura. Fumesua is situated in Ejisu-Juabeng District in the Ashanti Region (Latitude 6°43'N; Longitude 1°36'W) with an elevation of 228 meters above sea level (ASL), and falls within the semi-deciduous Forest ecological zone of Ghana. Ejura is situated in Ejura-Sekyedumasi District in the Ashanti Region (Latitude 7°24'N; Longitude 1°21'W) with an elevation of 225 meters above sea level (MoFA, 2013), and falls within the Forest-Savannah transition zone. The two locations experience a bi-modal rainfall, with the major season stretching from April through July and minor from September to December (Table 3.1). Fumesua is characterized by Ferric acrisols, while Ejura is characterized by Forest/savanna ochrosols soils (FAO/UNESCO Legend, 1986).

Table 3.1: Monthly climatic data of the study locations for the major (April to July) and minor (September to December) cropping seasons of 2014

	Fumesua				Ejura			
Months (2014)	**Rainfall (mm)**	**Tmax. (ºC)**	**Tmin. (ºC)**	**RH (%)**	**Rainfall (mm)**	**Tmax. (ºC)**	**Tmin. (ºC)**	**RH (%)**
April	128.6	33.3	24.4	68.0	165.3	35.0	25.5	60.5
May	103.4	31.6	24.2	73.0	153.2	33.1	25.1	72.5
June	270.0	30.5	23.9	75.5	365.6	33.2	25.1	75.0
July	91.4	28.3	22.8	79.5	81.0	30.0	24.1	77.5
September	162.9	28.9	22.7	79.0	214.2	30.0	23.8	81.0
October	138.2	30.2	23.4	75.0	82.2	32.3	24.8	70.0
November	107.2	31.6	23.8	72.0	39.3	32.7	24.8	70.5
December	10.8	31.8	22.9	64.5	0.0	34.1	22.8	54.5

Source: Ghana Meteorological Agency

3.1.1 Cropping History of the Experimental Sites

The experimental site at Fumesua was cultivated with yam, while the site at Ejura was cultivated with cowpea during the previous cropping season.

3.1.2 Soil Sampling and Analysis

Soil samples were randomly collected at each of the experimental sites at a depth of 0-25cm. The samples from each site was then bulked together and placed in a labeled polythene bag and were taken to the Soil Testing Laboratory at the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST) for analysis. Prior to the chemical analysis, the samples were separately air-dried, ground, and filtered through a 2 mm sieve. The soil samples were analyzed using standard laboratory procedures (Table 4.1). Soil pH (1:1 soil/water ratio) was measured with a pH meter. Available phosphorus was determined using the Bray-1 method (Bray and Kurtz, 1945); organic carbon was determined by the modified Walkley-Black Wet oxidation method as outlined by Nelson and Sommers (1982), and total nitrogen by the Kjeldahl digestion method (Bremner and Mulvaney, 1982; Okelabo *et al*., 1993). Exchangeable cations (Ca, Mg, K and Na) were estimated by spectrophotometry (Moss, 1961; Black, 1965). Exchangeable acidity (Al^{+}, H^{+}) was determined by titration method.

3.2 Experimental Design

The field trial was laid out in Lattice Square (7x7) Design with three replications per location. Each experimental unit was a four-row plot measuring 4.0 m long, spaced at 0.40m x 0.20m between and within rows, respectively, with an estimated 20 hills per row.

Seeds were sown at one seed per hill. Distance between subplots was 1.0 meter while distance between replications measured 1.5 meters. The total land area of each experimental site measured (34m x 46.2m) 1,570.8m^2.

3.3 Groundnut Genotypes used in the study

A total of forty-nine groundnut genotypes (Table 3.3) were used in the study. Of the forty-nine genotypes, 39 were obtained from hybridization between three local varieties (Aprewa, Shitaochi and Nkatepa) and two improved varieties (Nkosour and Azivivi). In addition to the crosses, ten varieties were used as checks. These consisted of eight improved varieties: Nkosour, Azivivi, Obolo, Oboshie, Otuhia, Yenyawoso, Adepa, and Jenkaah; and two local varieities (Shitaochi and Kumawu). All of the planting materials were obtained from the Crops Research Institute (CRI).

3.3.1. Characteristics of the Groundnut Genotypes

Table 3.2 provides summary of basic quality traits of the twelve parental groundnut genotypes used in the study.

Table 3.2: Basic quality traits of the twelve parental groundnut genotypes used in the study.

Variety	Uses	Disease reaction		Growth habit	Days to Maturity	Yield potential	Approximate nutrient content
		Rosette virus disease	Cercospora leaf spots				
Oboshie (Improved)	Confectionery	Moderately tolerant	Moderately resistant	Semi-erect	105-110 days	2,600kg/ha	Protein: 34.13% Carbohydrates: 6.78% Oil: 46.49%
Jenkaah (Improved)	Roasted/cooked	Resistant	Resistant	Semi-erect	105-110 days	2,456kg/ha	Protein: 27.8% Carbohydrates: 18.1% Oil: 51.1%
Nkosour (Improved)	Roasted/cooked	Resistant	Tolerant	Semi-erect	105-110 days	2,282kg/ha	Protein: 27.5% Carbohydrates: 21.1% Oil: 48.8%
Obolo (Improved)	Confectionery	Resistant	Resistant	Semi-erect	105-110 days	2,700kg/ha	Protein: 34.13% Carbohydrates: 9.78% Oil: 46.40%
Azivivi (Improved)	Roasted/cooked	Resistant	Resistant	Semi-erect	105-110 days	2,900kg/ha	Has high protein and oil content
Otuhia (Improved)	Confectionery	Tolerant	Tolerant	Creeping	105-110 days	2,500kg/ha	Has high protein and oil content
Adepa (Improved)	Roasted/cooked	Tolerant	Tolerant	Semi-erect	105-110 days	2,200kg/ha	Protein: 24.77% Carbohydrates: 26.5% Oil: 43.00%
Yenyawoso (Improved)	Roasted/cooked	Tolerant	Tolerant	Semi-erect	90 days	2,700kg/ha	Has high protein and oil content
Aprewa (Local)	Roasted/cooked	Susceptible	Susceptible	Erect	90 days	903kg/ha	Protein: 24.87 Carbohydrates: 21.6% Oil: 48.30%
Nkatepa (Local)	Roasted/cooked	Susceptible	Susceptible	Semi-erect	98 days	748kg/ha	Protein: 22.76 Carbohydrates: 23.0% Oil: 49.30%

Table 3.2 continued

Shitaochi (Local)	Roasted/cooked	Susceptible	Susceptible	Semi-erect	90 days	1,038kg/ha	Protein: 20.09% Carbohydrates: 19.8% Oil: 54.65%
Kumawu (Local)	Roasted/cooked	Susceptible	Susceptible	Semi-erect	96 days	765kg/ha	Protein: 23.71% Carbohydrates: 22.9% Oil: 49.50%

Source: Crops Research Institute

3.3.2. Development of crosses/hybrid lines

The hybridization work began in early 2011 and was carried out by the Legumes Improvement Division of the Crops Research Institute in Kumasi. Hybrids were generated through manual emasculation and pollination techniques. The five parental materials used for the hybridization included three local farmers' preferred varieties; namely: Aprewa, Shitaochi and Nkatepa and were used as females; while two improved varieties: Nkosour and Azivivi were used as males. The five parental materials (Aprewa, Shitaochi, Nkatepa, Nkosour and Azivivi) are designated as Ap, Sh, Np, Nk and Az respectively in this report. The following crosses were carried out: Aprewa x Nkosour (Ap x Nk); Aprewa x Azivivi (Ap x Az); Shitaochi x Nkosour (Sh x Nk); Shitaochi x Azivivi (Sh x Az); and Nkatepa x Nkosour (Np x Nk). After the generation of the F_1 seeds, the hybrid lines were repeatedly selfed (self-pollinated) until a F_6 generation was obtained in 2013. A total of 39 improved lines (Table 3.3) were obtained from the hybridization. Some basic characteristics of the three local varieties (Aprewa, Shitaochi and Nkatepa) include early maturing, low to medium yielding, and have high oil content but are however susceptible to a number of diseases including rosette virus and *Cercospora* leaf spots. The two improved varieties (Nkosour and Azivivi) are high yielding, late maturing, have high oil and protein contents. They are also resistant to the rosette virus and the *Cercospora* leaf spots, and drought tolerant as well.

Table 3.3: List of 49 groundnut genotypes used in the study

Entry No.	Entry Name/ID.	Entry No.	Entry Name/ID.*
1	CRG-SH x AZ-3-13	26	CRG-NP x NK-3-13
2	CRG-AP x AZ-1-13	27	CRG-SH x NK-1-13
3	CRG-AP x AZ-8-13	28	CRG-AP x AZ-10-13
4	CRG-SH x AZ-7-13	29	Nkosour
5	CRG-SH x AZ-4-13	30	CRG-SH x AZ-1-13
6	CRG-AP x NK-2-13	31	CRG-AP x NK-9-13
7	CRG-SH x AZ-2-13	32	CRG-AP x NK-5-13
8	CRG-AP x AZ-13-13	33	CRG-AP x NK-4-13
9	CRG-AP x AZ-9-13	34	CRG-NP x NK-2-13
10	CRG-AP x NK-3-13	35	CRG-AP x AZ-16-13
11	CRG-AP x NK-10-13	36	CRG-SH x AZ-5-13
12	CRG-NP x NK-7-13	37	CRG-AP x AZ-4-13
13	Azivivi	38	CRG-AP x AZ-15-13
14	Shitaochi-Local	39	CRG-AP x NK-12-13
15	CRG-AP x AZ-11-13	40	CRG-SH x AZ-6-13
16	CRG-AP x AZ-6-13	41	CRG-AP x AZ-5-13
17	CRG-AP x AZ-3-13	42	CRG-SH x NK-2-13
18	CRG-AP x NK-6-13	43	Oboshie
19	CRG-AP x AZ-14-13	44	Obolo
20	CRG-AP x AZ-2-13	45	Yenyawoso
21	CRG-AP x AZ-12-13	46	Adepa
22	CRG-AP x NK-11-13	47	Jenkaar
23	CRG-AP x NK-1-13	48	Kumawu-Local
24	CRG-AP x NK-8-13	49	Otuhia
25	CRG-AP x AZ-7-13		

*ID = Identification

3.4 Agronomic/Husbandry practices

The experimental sites were cleared, ploughed and then harrowed. These activities were carried out to manage weeds, provide good soil aeration and to obtain good seedling emergence and root penetration. The study was carried out during the major and minor seasons of 2014. For the major season, field layout at Fumesua was carried out on 14 April 2014, followed by the sowing of seeds on 15 April 2014; while field layout and sowing of seeds at Ejura was carried out on 16 and 17 April 2014, respectively. For the minor season, seeds cultivation at Fumesua and Ejura were respectively carried out on September 10 and 12, 2014. Seeds were sown at one seed per hill at a depth of about 5cm. The inter- and intra-row distances were 0.40m and 0.20m, respectively. Initial manual weeding was carried out by hand hoeing 21days after planting at each location; followed by three successive manual weeding at three-week interval during the growth period. Earthing up operations was carried out at five weeks after planting (WAP).

Fertilizer (NPK-23-10-10) application at the two locations was done two week after planting using side placement method at a rate of 20kg N ha^{-1}; while the application of oyster shell (calcium) was carried out six weeks after planting (during peg formation) at a rate of 100kg Ca ha^{-1}. All recommended agronomic practices were carried out during the growing periods, as and when necessary.

3.5 Data Collection

The following data (agronomic and post-harvest) were collected during the pre-harvest and post-harvest stages.

3.5.1 Days to 50% flowering: This parameter was determined visually by counting the number of days when 50% of the plants in a subplot had opened flowers.

3.5.2 Number of branches per plant: The number of branches produced by a plant was determined by counting the number of primary, secondary, and tertiary branches on five tagged plants in the two middle rows and was carried out eight weeks after planting.

3.5.3 Plant height: Plant height was measured with a meter rule on 5 tagged plants in the two middle rows of each subplot. Height was measured from the base of the plant to the topmost leaf bud on the main stem and the mean height was expressed in centimeters. This parameter was taken twice-at 8 WAP and at crop maturity.

3.5.4 Days to maturity: This parameter was taken when about 80% of the pods on a sample plant were matured. 1-2 plants were uprooted in each subplot, and the number of matured pods indicated by the dark markings of the internal shell wall.

3.5.5 Number of pods per plant (filled and unfilled): The numbers of filled and empty pods (pops) on five tagged plants from the two middle rows were counted separately and the mean recorded. This parameter was taken at harvest.

3.5.6 Pod yield per plant: The weights of dry filled pods of five tagged plants were weighed and the mean recorded in grams. This parameter was taken at one week after harvest.

3.5.7 Number of seeds per pod: The number of seeds per pod was determined by randomly selecting 100 pods from a subplot. The pods were then shelled and

the number of seeds counted. The total seed number was divided by the pod number (100) to obtain the average seed per pod.

3.5.8 100 pod weight: 100 sundried matured pods were randomly selected from each treatment and the weight recorded in grams.

3.5.9 Shelling Percentage: 100 matured pods were selected from each treatment (subplot) and weighed in grams. Seeds from the 100 pods were also weighed in grams. The shelling percentage was then obtained by dividing the weight of seeds by the weight of the 100 pods, and the quotient multiply by 100 as follows:

$$\text{Shelling \%} = \frac{\text{seed mass (wt)}}{\text{pod mass (wt)}} \text{ x } 100$$

3.5.10 Pod Yield (Kg/ha): Dry pod weight of all harvested plants from the two central rows (4mx0.8m= 3.2m^2) were recorded and then converted to pod yield per hectare (kg/ha) by using the formula:

$$\text{Pod yield (kg/ha)} = \frac{\text{pod yield (kg)}}{\text{Harvested area (m}^2\text{)}} \text{ x } 10{,}000\text{m}^2$$

3.6 Data Analysis

Data gathered during the studies were analyzed using the Statistical Analysis System (SAS) version 9.2 (SAS Institute Incorporated, 2002). Data from each location were subjected to Analysis of Variance (ANOVA) individually to explore differences among entries for all traits and pooled across locations to determine G x E interactions. Means separation was carried out using least significant difference (LSD). Correlations among pod yield and yield contributing traits were examined. GGE biplot analysis (Yan, 2001) was used to assess yield stability among the groundnut genotypes.

CHAPTER FOUR

4.0 RESULTS

4.1 Results of Soil Analyses

The results of the analyses of soil samples from the test locations are presented in Table 4.1. Soils of Ejura recorded slightly higher values for organic carbon, organic matters and available P than samples from Fumesua; while soils of Fumesua recorded higher values of total N, exchangeable cations, exchangeable acidity, and pH than soils of Ejura (Table 4.1).

Table 4.1: Results from soil analyses of soil samples from Fumesua and Ejura in 2014

				Exchangeable Cations (cmol/kg)				Exchangeable Acidity (cmol/kg)			
Locations	**% Org. carbon**	**% Org. matter**	**% Total N**	**K**	**Na**	**Ca**	**Mg**	**Al^+**	**H^+**	**Avail. P (mg/kg)**	**PH**
FUMESUA	1.54	2.65	0.22	0.38	0.17	6.88	1.34	0.50	0.84	16.46	6.77
EJURA	1.70	2.92	0.13	0.21	0.10	4.76	0.44	0.50	0.67	17.36	6.36

Courtesy: Soil Science Laboratory, Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology

4.2 Mean squares for pod yield for the two test environments and seasons

The mean square values for genotypes at the two separate locations and two seasons for pod yield showed that there were highly significant differences ($p<0.01$) among genotypes during the major season at the two locations and highly significant difference ($p<0.01$) at Fumesua during the minor season, and significant differences ($p<0.05$) at Ejura for the minor season (Table 4.2).

Table 4.2: Mean squares for pod yield (kg ha^{-1}) of 49 groundnut genotypes evaluated at two locations in Ghana during the major and minor cropping seasons of 2014

		Major Season		Minor Season	
		Fumesua	**Ejura**	**Fumesua**	**Ejura**
Source of Variation	Degrees of freedom	Mean Squares			
Replication	2	11504512	1049039	2337091	453665
Block (Rep.)	18	1028785	179659	396399	116597
Genotype	48	658962**	313321**	206411**	48777*
Residual	78	296827	89309	97215	34755
Total	146				
CV %		26.60	40.10	24.00	24.90

****** ($p<0.01$) highly significant; * ($p<0.05$) significant

4.3 Mean performance of genotypes evaluated at two locations in Ghana during the major and minor cropping seasons of 2014

4.3.1 Comparison of mean performance across the two test locations and seasons

The results from the analyses of the individual yield data collected from each test location and season showed that of the two locations; pod yield at Fumesua was higher than Ejura during the two cropping seasons (major and minor seasons of 2014). For the major season, pod yield at Fumesua averaged 2,050.20 kg ha^{-1}, approximately three times (3x) more than the mean pod yield obtained at Ejura (745.20 kg ha^{-1}) during the same period (Appendices 1 & 2). For the minor season, the mean pod yield at Fumesua was 1,300.80 kg ha^{-1}, approximately two times (2x) more than the averaged pod yield at Ejura (748.70 kg ha^{-1}) (Appendices 1 & 2). The results indicate that Fumesua provides fairly optimum environmental conditions for the cultivation of groundnuts, which may be attributed to residual effects of previously used fertilizers, adequate organic matter content in the soils and optimum rainfall.

4.3.2 Mean performance of genotypes at Fumesua for the two seasons

From the analysis, significant differences ($p<0.01$) were observed in the performance of genotypes for pod yield at Fumesua for the two cropping seasons. Table 4.3 contained the lists of the top ten high yielding and the bottom ten low yielding genotypes at Fumesua for the two cropping seasons. The mean pod yield at Fumesua for the major season was 2,050.20 kg ha^{-1}. The improved genotype, CRG-NP x NK-2-13 emerged as the best genotype with an average pod yield of 3,026.04 kg ha^{-1}; while Adepa (a check) emerged as the lowest yielding genotype with an average yield of 721.13 kg ha^{-1}. The best genotype (CRG-NP x NK-2-13), out yielded the best check (Oboshie) by 10.35%, and performed 47.6% more than the mean (2,050.20 kg ha^{-1}). In contrast, the least performing genotype, Adepa yielded 64.83% less than the mean (Table 4.3). The best genotype (CRG-NP x NK-2-13) was however not statistically different from the other top nine genotypes during the major season (Table 4.3).

For the minor season, the mean pod yield of the genotypes was 1,300.80 kg ha^{-1} (Table 4.3). The improved genotype, CRG-AP x NK-9-13 emerged as the best genotype with a mean pod yield of 2,097.69 kg ha^{-1}, outperforming the best check (Otuhia) by 11.51%, and 61.30% more than the mean (1,300.80 kg ha^{-1}). Shitaochi (a check) emerged as the lowest yielding genotype with an average yield of 757.74 kg ha^{-1}, 41.75% less than the mean (1,300.80 kg ha^{-1}) (Table 4.3). The best genotype (CRG-NP x NK-9-13) was not significantly different in yield performance from the other top nine genotypes during the minor season except Nkosour and CRG-SH x NK-1-13 (Table 4.3). Overall, the observed mean performances of the genotypes were higher at Fumesua than Ejura for the two seasons.

Table 4.3: Pod yield (kg ha^{-1}) of the top 10 and bottom 10 genotypes evaluated in Fumesua during the major and minor cropping seasons of 2014

Major Season			Minor Season		
Entry No.	**Genotypes**	**Yield (Kg/Ha)**	**Entry No.**	**Genotypes**	**Yield (Kg/Ha)**
Top 10 high yielding genotypes			**Top 10 high yielding genotypes**		
34	CRG-NP x NK-2-13	3,026.04	31	CRG-AP x NK-9-13	2,097.69
20	CRG-AP x AZ-2-13	2,871.39	49	Otuhia	1,856.21
3	CRG-AP x AZ-8-13	2,818.86	10	CRG-AP x NK-3-13	1,833.63
8	CRG-AP x AZ-13-13	2,784.60	22	CRG-AP x NK-11-13	1,826.26
43	Oboshie	2,712.87	30	CRG-SH x AZ-1-13	1,719.75
15	CRG-AP x AZ-11-13	2,708.93	9	CRG-AP x AZ-9-13	1,610.53
48	Kumawu-Local	2,651.64	6	CRG-AP x NK-2-13	1,607.4
1	CRG-SH x AZ-3-13	2,612.54	17	CRG-AP x AZ-3-13	1,553.46
17	CRG-AP x AZ-3-13	2,549.48	29	Nkosour	1,516.89
14	Shitaochi-Local	2,509.90	27	CRG-SH x NK-1-13	1,493.12
Bottom 10 low yielding genotypes			**Bottom 10 low yielding genotypes**		
39	CRG-AP x NK-12-13	1,519.31	47	Jenkaar	1,051.67
31	CRG-AP x NK-9-13	1,480.43	4	CRG-SH x AZ-7-13	1,043.08
42	CRG-SH x NK-2-13	1,463.17	28	CRG-AP x AZ-10-13	1,042.08
47	Jenkaar	1,435.38	43	Oboshie	1,028.05
33	CRG-AP x NK-4-13	1,423.96	32	CRG-AP x NK-5-13	1,011.12
11	CRG-AP x NK-10-13	1,313.62	39	CRG-AP x NK-12-13	971.06
25	CRG-AP x AZ-7-13	1,231.62	23	CRG-AP x NK-1-13	947.62
23	CRG-AP x NK-1-13	1,175.48	45	Yenyawoso	926.79
26	CRG-NP x NK-3-13	1,163.17	24	CRG-AP x NK-8-13	906.44
46	Adepa	721.13	14	Shitaochi-Local	757.74
Grand mean*		**2,050.20**			**1,300.80**
LSD (0.05)		975.90			558.50
CV (%)		26.60			24.00

* Mean stated is for all 49 groundnut genotypes used in the study

4.3.3 Mean performance of genotypes at Ejura for the two seasons

There were highly significant differences ($p<0.01$) among genotypes for pod yield at Ejura during the major season and significant differences ($p<0.05$) during the minor season. Table 4.4 contained the lists of the top ten high yielding and the bottom ten low yielding genotypes at Ejura for the two cropping seasons. For the major season, the mean

pod yield at Ejura was 745.20 kg ha^{-1} (Table 4.4). Otuhia (a check) emerged as the best performing genotype with an average pod yield of 1,672.81 kg ha^{-1}; while the improved line, CRG-NP x NK-7-13 emerged as the lowest yielding genotype with an average yield of 249.33 kg ha^{-1}. Otuhia out yielded the best improved line (CRG-SH x NK-1-13) by 11.33%, and performed 124.5% more than the mean (745.20 kg ha^{-1}) for the major season (Table 4.4). In contrast, the least performer, CRG-NP x NK-7-13 (249.33 kg ha^{-1}) yielded 66.54% less than the mean (745.20 kg ha^{-1}) at Ejura (Table 4.4). The best genotype (Otuhia) was not significantly different in yield performance from the other top nine genotypes during the major season except Yenyawoso, CRG-AP x NK-8-13, and CRG-AP x AZ-16-13 (Table 4.4).

The mean pod yield at Ejura for the minor season was 748.70 kg ha^{-1}; 0.47% (3.5kg ha^{-1}) more than the mean (745.20 kg ha^{-1}) at the same location for the major season (Table 4.4). The improved line, CRG-SH x AZ-4-13 emerged as the best genotype with an averaged pod yield of 1,114.73 kg ha^{-1}; 48.9% more than the mean (748.70 kg ha^{-1}); while another improved line, CRG-AP x NK-10-13 emerged as the lowest yielding genotype with an average yield of 434.67 kg ha^{-1}; 41.94% less than the mean pod yield (748.70 kg ha^{-1}). All of the top 10 high yielding genotypes at Ejura during the minor season were improved lines (Table 4.4). The best genotype, CRG-SH x AZ-4-13 was not statistically different from the other top nine genotypes.

Table 4.4: Pod yield (kg ha^{-1}) of the top 10 and bottom 10 genotypes evaluated in Ejura during the major and minor cropping seasons of 2014

Major Season			Minor Season		
Entry No.	**Genotypes**	**Yield (Kg/Ha)**	**Entry No.**	**Genotypes**	**Yield (Kg/Ha)**
	Top 10 high yielding genotypes			**Top 10 high yielding genotypes**	
49	Otuhia	1,672.81	5	CRG-SH x AZ-4-13	1,114.73
27	CRG-SH x NK-1-13	1,483.33	26	CRG-NP x NK-3-13	1,047.14
29	Nkosour	1,439.99	19	CRG-AP x AZ-14-13	989.55
13	Azivivi	1,277.34	21	CRG-AP x AZ-12-13	943.42
26	CRG-NP x NK-3-13	1,246.95	27	CRG-SH x NK-1-13	927.57
40	CRG-SH x AZ-6-13	1,223.20	25	CRG-AP x AZ-7-13	921.99
46	Adepa	1,217.45	36	CRG-SH x AZ-5-13	905.39
45	Yenyawoso	1,040.62	42	CRG-SH x NK-2-13	896.32
24	CRG-AP x NK-8-13	1,035.38	33	CRG-AP x NK-4-13	858.63
35	CRG-AP x AZ-16-13	1,017.71	34	CRG-NP x NK-2-13	853.01
	Bottom 10 low yielding genotypes			**Bottom 10 low yielding genotypes**	
10	CRG-AP x NK-3-13	429.20	28	CRG-AP x AZ-10-13	625.15
44	Obolo	423.81	41	CRG-AP x AZ-5-13	616.22
5	CRG-SH x AZ-4-13	405.28	39	CRG-AP x NK-12-13	602.01
T14	Shitaochi-Local	403.72	2	CRG-AP x AZ-1-13	586.38
22	CRG-AP x NK-11-13	392.22	32	CRG-AP x NK-5-13	584.23
18	CRG-AP x NK-6-13	369.20	30	CRG-SH x AZ-1-13	580.25
7	CRG-SH x AZ-2-13	347.88	47	Jenkaar	558.89
39	CRG-AP x NK-12-13	286.53	10	CRG-AP x NK-3-13	550.07
11	CRG-AP x NK-10-13	285.83	46	Adepa	500.52
12	CRG-NP x NK-7-13	249.33	11	CRG-AP x NK-10-13	434.67
Grand mean		**745.20**			**748.70**
LSD (0.05)		535.31			333.94
CV (%)		40.10			24.90

* Mean stated is for all 49 groundnut genotypes used in the study

4.4 Combined mean square analysis of genotypes for pod yield and other agronomic traits evaluated across two locations in Ghana

4.4.1 Percentage mean square variance for yield attributed to the sources of variation

The results from the combined analysis of variance showed that location main effects were the key cause of variation for pod yield. Percentage contribution of mean square

variance attributed to environment was 97.22%; followed by other factors under block (1.21%), genotype by environment interaction (0.61%), genotypes (0.58%), and error (0.38%) as shown in Table 4.5.

Table 4.5: Combined variance component analysis with the proportion of total mean square variance attributed to the sources of variation for pod yield of 49 genotypes evaluated across two locations in Ghana during the major and minor seasons of 2014

	Pod Yield		
Source of Variation	**Degree of Freedom**	**Mean squares**	**% Mean squares**
Location	3	56152859.5**	97.22
Block (Rep.)	20	697363.9**	1.21
Genotype	48	336135.2*	0.58
Gen. x Loc.	144	352647.9**	0.61
Error	372	217040.8	0.38
Total	587		100.00
CV %			38.49
LSD (0.05)			373.99

****** ($p<0.01$) highly significant; * ($p<0.05$) significant

4.4.2 Pod yield

Results from the combined analysis of variance (ANOVA) for pod yield showed that there was significant difference ($p<0.05$) between genotypes; and highly significant difference ($p<0.01$) between locations, and genotype and location interaction (Table 4.5). Averaged across the test locations, the mean pod yield was 1,210.41 kg ha^{-1} (Table 4.6). Otuhia emerged as the best performing genotype across all the test locations with an average yield of 1,530.7 kg ha^{-1}; 26.5% more than the grand mean (1,210.41 kg ha^{-1}). The improved genotype, CRG-AP x AZ-14-13 was the second best performing genotype across all the test locations with an average yield of 1,490.5 kg ha^{-1}; 23.14% more than the grand mean (1,210.41 kg ha^{-1}). CRG-AP x NK-10-13 emerged as the least performing genotype with an average yield of 771.9 kg ha^{-1}; 36.23% less than the grand mean

(1,210.41 kg ha^{-1}) (Table 4.6). Among the improved lines, CRG-AP x AZ-14-13 emerged as the highest yielding genotype (1,490.50 kg ha^{-1}) and as the second highest yielder, overall (Table 4.6). CRG-AP x NK-10-13 emerged as the least performing genotype (771.9 kg ha^{-1}) and 49th place, overall (Appendix 3). Among the checks, Otuhia emerged as the best performer (1,530.7 kg ha^{-1}) and the highest yielder (1st place) of all 49 genotypes; while Adepa emerged as the lowest yielding check (974.1 kg ha^{-1}) and 45th place, overall (Appendix 3).

Table 4.6: Mean performance for pod yield (kg ha^{-1}) of the top 10 and bottom 10 genotypes evaluated across the two locations during the major and minor cropping seasons of 2014

Entry No.	Genotypes	Rank	Yield (Kg/Ha)
	Top 10 high yielding genotypes		
49	Otuhia	1st	1,530.7
19	CRG-AP x AZ-14-13	2nd	1,490.5
34	CRG-NP x NK-2-13	3rd	1,486.7
27	CRG-SH x NK-1-13	4th	1,445.8
43	Oboshie	5th	1,441.1
40	CRG-SH x AZ-6-13	6th	1,408.6
17	CRG-AP x AZ-3-13	7th	1,390.4
29	Nkosour	8th	1,375.3
20	CRG-AP x AZ-2-13	9th	1,372.7
48	Kumawu-Local	10th	1,372.5
	Bottom 10 low yielding genotypes		
32	CRG-AP x NK-5-13	40th	1,068.4
36	CRG-SH x AZ-5-13	41st	1,052.2
47	Jenkaar	42nd	1,043.0
22	CRG-AP x NK-11-13	43rd	1,031.3
2	CRG-AP x AZ-1-13	44th	1,016.9
46	Adepa	45th	974.1
42	CRG-SH x NK-2-13	46th	938.4
23	CRG-AP x NK-1-13	47th	899.1
39	CRG-AP x NK-12-13	48th	802.1
11	CRG-AP x NK-10-13	49th	771.9
Grand mean			**1,210.41**
LSD (0.05)			373.990
CV%			38.490

* Mean stated is for all 49 groundnut genotypes used in the study

4.4.3 Days to 50% flowering

The results from the combined analysis of variance for days to 50% flowering showed that there was highly significant difference ($p<0.01$) between locations, genotypes, and their interactions (Table 4.7a). Averaged across the test locations, the mean day to 50% flowering was 30.0 days. The days to 50% flowering ranged from 27.0 to 33.0 days. Overall, the improved genotype, CRG-AP x AZ-3-13 took less days (27.0) to achieved 50% flowering; while Jenkaar, a check took longer days (33.0) to reach 50% flowering (Appendix 3). Among the improved genotypes, CRG-AP x AZ-3-13 took less days (27.0) to reach 50% flowering, while CRG-NP x NK-3-13 took longer days (33.0). For the checks, Yenyawoso was the first to achieve 50% flowering (28.0 days), while Jenkaar was the last to achieve 50% flowering (33.0 days) (Appendix 3).

4.4.4 Days to Maturity

Highly significant differences ($p<0.01$) were observed between locations, genotypes, and their interactions for days to maturity (Table 4.7a). The mean day to maturity was 97.0 days. Of the 49 groundnut genotypes, CRG-AP x AZ-3-13 was the first to reach maturity (89.0 days); while Obolo, a check was the latest to reach maturity (107.0 days) (Appendix 3). Among the improved lines, CRG-AP x AZ-3-13 took less days (89.0) to reach maturity; while CRG-SH x NK-2-13 took more days (106.0) to reach maturity. Among the checks, Obolo took more days (107.0) to reach maturity; while Shitaochi took less days (91.0) (Appendix 3). Overall, 30 (61.20%) of the 49 genotypes (28 improved lines, and 2 checks) reach maturity lower than the mean day (97.0), and ranged from 89.0 to 96.0 days; while 19 genotypes (38.80%), (11 improved genotypes, and 8 checks) exceeded the mean day (97.0), and ranged from 101.0 to 107.0 days (Appendix 3).

4.4.5 Plant height

Results from the combined ANOVA for plant height showed highly significant differences ($p<0.01$) between locations, genotypes, and their interactions (Table 4.7a). The mean plant height was 40.7cm. Plant height ranged from the lowest (31.3cm) recorded on CRG-AP x NK-12-13 to the highest (50.1cm) recorded on CRG-AP x NK-10-13 (Appendix 4). Among the improved lines, CRG-AP x NK-10-13 recorded the tallest plant (50.1cm); while CRG-AP x NK-12-13 recorded the shortest plant (31.3cm). Among the checks, Kumawu recorded the tallest plant (43.3cm); while Jenkaar recorded the shortest plant height (32.4cm) (Appendix 4).

4.4.6 Branch number per plant

From the combined analysis of variance, highly significant differences ($p<0.01$) were observed between locations, genotypes, and their interaction for number of branches per plant (Table 4.7a). The mean number of branches per plant was 10.1. Overall, Jenkaar recorded the highest branch number per plant (17.8); while CRG-AP x NK-6-13 recorded the least branch number (7.4) (Appendix 4). Among the improved genotypes, CRG-SH x NK-1-13 produced the highest branch number (15.7); while CRG-AP x NK-6-13 produced the least branch number (7.4). For the checks, Jenkaar produced the highest branch number per plant (17.8); while Yenyawoso produced the least number of branches per plant (8.6) (Appendix 4).

4.4.7 Number of pods per plant (filled)

There were highly significant differences ($p<0.01$) between locations, and genotypes for number of pods per plant. However, there was no statistical difference between their

interactions (Table 4.7a). The number of pod per plant ranged from the lowest (17.6) recorded on CRG-AP x NK-12-13 to the highest (30.7) recorded on CRG-SH x AZ-6-13 (Appendix 4). The mean number of pods per plant was 24.0 (Table 4.7a). Among the improved lines, CRG-SH x AZ-6-13 produced the highest pod number per plant (30.7); while CRG-AP x NK-12-13 produced the least pod number per plant (17.6). For the checks, Kumawu produced the highest pod number per plant (27.0); while Adepa produced the least number of pods per plant (18.3) (Appendix 4).

Table 4.7a: Combined mean squares for agronomic parameters of 49 groundnut genotypes evaluated across two locations in Ghana during the major and minor seasons of 2014

		Mean Squares				
SoV	**DF**	**DFF**	**DM**	**PH**	**BNP**	**PNP**
Location	3	285.01**	2448.20**	5493.94**	678.97**	4832.80**
Block (Rep.)	20	10.58 **	65.66*	48.40*	14.40**	106.84*
Genotype	48	30.73**	560.58**	255.03**	65.41**	90.34**
Gen. x Loc.	144	11.54**	84.84**	40.58**	12.42**	51.90
Error	372	3.60	27.94	20.11	4.47	50.13
Total	587					
CV %		6.453	5.501	11.020	20.929	29.596
LSD (0.05)		1.521	4.243	3.600	1.697	5.684
Grand mean		**30.00**	**97.00**	**40.70**	**10.10**	**24.00**

SoV = Source of Variation; DF = Degree of Freedom; DFF = Days to 50% flowering; DM = Days to Maturity; PH = Plant height; BNP = Branch number per plant; PNP = Number of pod per plant; ****** ($p<0.01$) highly significant; * ($p<0.05$) significant

4.4.8 Pod yield per plant

Results from the combined analysis of variance for pod yield per plant showed highly significant differences ($p<0.01$) between locations, and genotypes; but no significant difference between their interactions (Table 4.7b). Pod yield per plant ranged from the lowest (14.6g) recorded on CRG-AP x NK-12-13 to the highest (27.4g) recorded on Otuhia (Appendix 4). The mean pod yield per plant was 21.61g (Table 4.7b). Among the improved lines, CRG-AP x NK-6-13 recorded the highest pod yield per plant (26.8g); while CRG-AP x NK-12-13 recorded the lowest pod yield per plant (14.6g). Among the checks, Otuhia recorded the highest pod yield per plant (27.4g); while Adepa recorded the lowest pod yield per plant (17.9g) (Appendix 4).

4.4.9 100 pod weight

Highly significant differences ($p<0.01$) were observed between locations, genotypes, and their interactions for 100 pod weight (Table 4.7b). The values of 100 pod weight ranged from the lowest weight (67.3g) recorded on CRG-AP x NK-9-13 to the highest weight (151.7g) recorded on Oboshie (Appendix 5). The mean 100 pod weight was 95.83g. Among the improved lines, CRG-SH x NK-1-13 recorded the highest weight (114.0g); while CRG-AP x NK-9-13 recorded the lowest weight (67.3g). Among the checks, Oboshie recorded the highest 100 pod weight (151.7g); while Shitoachi recorded the lowest 100 pod weight (87.7g) (Appendix 5).

4.4.10 Number of seeds per pod

From the combined analysis of variance, highly significant differences ($p<0.01$) were observed between locations, genotypes, and their interactions for number of seeds per pod

(Table 4.7b). The mean seed number per pod was 1.85. Overall, CRG-AP x AZ-4-13 and Shitoachi recorded the highest number of seeds per pod (2.1); while CRG-AP x NK-12-13 recorded the least number of seeds per pod (1.5) (Appendix 5). Among the improved lines, CRG-AP x AZ-4-13 produced the highest number of seeds per pod (2.1); while CRG-AP x NK-12-13 produced the lowest seed number per pod (1.5). For the checks, Shitoachi produced the highest seed number per pod (2.1); while Adepa produced the least number of seeds per pod (1.6) (Appendix 5).

4.4.11 Shelling percentage (%)

Results from the combined analysis of variance for shelling percentage showed highly significant differences ($p<0.01$) between locations, genotypes, and their interactions (Table 4.7b). The mean shelling percentage was 69.0%. Averaged across the test locations, CRG-AP x NK-2-13 recorded the highest mean shelling percentage (75.0%), while CRG-AP x NK-12-13 recorded the lowest shelling percentage (52.0%) (Appendix 5). Among the improved genotypes, CRG-AP x NK-2-13 recorded the highest shelling percentage (75.0%); while CRG-AP x NK-12-13 recorded the lowest shelling percentage (52.0%). Among the checks, Shitaochi recorded the highest mean shelling percentage (70.0%); while Obolo recorded the lowest shelling percentage (59.0%) (Appendix 5).

Table 4.7b: Combined mean squares for agronomic parameters of 49 groundnut genotypes evaluated across two locations in Ghana during the major and minor seasons of 2014

		Mean Squares			
SoV	**DF**	**PYP**	**100 PW**	**SNP**	**SP**
Location	3	6334.80**	12677.86**	0.809**	0.163**
Block (Rep.)	20	116.62**	532.90**	0.0525*	0.0072**
Genotype	48	75.51**	1969.31**	0.15204**	0.0206**
Gen. x Loc.	144	49.01	252.10**	0.0561**	0.006**
Error	372	46.87	143.11	0.032	0.00221
Total	587				
CV %		31.674	12.484	9.650	6.857
LSD (0.05)		5.496	9.603	0.143	0.038
Grand mean		**21.61**	**95.83**	**1.85**	**0.69**

SoV = Source of Variation; DF = Degree of Freedom; PYP = Pod yield per plant; 100 PW = 100 pod weight; SNP = Number of Seed per pod; SP = Shelling percentage (%)
** ($p<0.01$) highly significant; * ($p<0.05$) significant

4.5 Correlation between pod yield and traits of agronomic importance

Results on correlation between pod yield and other important agronomic traits are presented in Table 4.8. The correlation study revealed that pod yield/ha was positively correlated to pod yield per plant, 100-pod weight, number of pods per plant, number of seeds per pod, and shelling percentage (Table 4.8). The associations were highly significant ($p<0.01$). The correlation between pod yield/ha and number of branches per plant was significant ($p<0.05$). Pod yield per plant had the highest correlation ($r = 0.709$) with pod yield/ha; followed by number of pods per plant ($r = 0.608$), 100-pod weight ($r = 0.509$) and shelling percentage ($r = 0.257$). Number of branches per plant had a weak correlation with pod yield. Days to 50% flowering was weakly negative and significantly

($p<0.01$) correlated with pod yield ($r = -0.122$); while days to maturity had weak negative correlated with pod yield ($r = -0.067$) but not significant (Table 4.8). Number of pods per plant was positively correlated with pod yield per plant ($r = 0.854$) (Table 4.8).

Table 4.8: Correlations between pod yield and other agronomic traits

Traits	PY/Ha	PYP	100 PW	PNP	SNP	SP	DFF	DM
PY/Ha	1.000							
PYP	0.709**							
100 PW	0.509**	0.595**						
PNP	0.608**	0.854**	0.269**					
SNP	0.141*	0.193**	0.244**	0.195**				
SP	0.257**	0.245**	0.159**	0.282**	0.600**			
DFF	-0.122*	-0.031	0.186**	-0.073	0.043	-0.008		
DM	-0.067	-0.011	0.232**	-0.053	-0.051	-0.024	0.609**	
BNP	0.094*	0.097*	0.113**	0.088	0.081	0.177**	0.153**	0.275**

PY/Ha = pod yield/ha; PYP = Pod yield per plant; 100 PW = 100 pod weight; PNP = Number of pod per plant; SNP = Number of Seed per pod; SP = Shelling percentage (%); DFF = Days to 50% flowering; DM = Days to Maturity; BNP = Branch number per plant; ****** ($p<0.01$) highly significant; ***** ($p<0.05$) significant

4.6 Selection of superior genotypes by ranking method

In line with the objectives of the studies, the selection of superior genotypes was based on two criteria. The first criteria was based on yield performance only and involved all 49 genotypes used in the study (Table 4.9); while the second criteria considered both yield performance and days to maturity (mainly early maturing) of improved lines (Table 4.10). Table 4.9 contained the list of the best 15 performing genotypes (checks and improved lines) based on averaged pod yield (kg ha^{-1}) across all test locations.

Table 4.9: List of the best 15 genotypes based on averaged pod yield (kg ha^{-1}) across the test locations

No.	Entry No.	Genotypes	Rank	Yield (Kg/Ha)	Days to Mat.
1	49	Otuhia	1st	1,530.7	106.0
2	19	CRG-AP x AZ-14-13	2nd	1,490.5	90.0
3	34	CRG-NP x NK-2-13	3rd	1,486.7	104.0
4	27	CRG-SH x NK-1-13	4th	1,445.8	105.0
5	43	Oboshie	5th	1,441.1	106.0
6	40	CRG-SH x AZ-6-13	6th	1,408.6	104.0
7	17	CRG-AP x AZ-3-13	7th	1,390.4	89.0
8	29	Nkosour	8th	1,375.3	106.0
9	20	CRG-AP x AZ-2-13	9th	1,372.7	90.0
10	48	Kumawu-Local	10th	1,372.5	92.0
11	31	CRG-AP x NK-9-13	11th	1,361.7	104.0
12	8	CRG-AP x AZ-13-13	12th	1,359.6	90.0
13	38	CRG-AP x AZ-15-13	13th	1,355.6	90.0
14	21	CRG-AP x AZ-12-13	14th	1,343.2	91.0
15	44	Obolo	15th	1,322.4	107.0
Grand Mean*				**1,210.41**	**97.00**

*Mean stated is the grand mean for all 49 genotypes across all test locations

Table 4.10 contained the list of improved hybrid genotypes based on yield performance (kg ha^{-1}) and early maturity (less than 97 days) as well as their overall rank among all 49 genotypes. The best ten (10) high yielding and early maturing improved hybrid lines were identified based on their mean performances across all the test locations.

Table 4.10: List of the best 10 improved hybrid genotypes based on averaged pod yield (kg ha^{-1}) and early maturity across the test locations

No.	Entry No.	Genotypes	Rank	Yield (Kg/Ha)	Days to Maturity
1.	19	CRG-AP x AZ-14-13	2nd	1,490.5	90.0
2.	17	CRG-AP x AZ-3-13	7th	1,390.4	89.0
3.	20	CRG-AP x AZ-2-13	9th	1,372.7	90.0
4.	8	CRG-AP x AZ-13-13	12th	1,359.6	90.0
5.	38	CRG-AP x AZ-15-13	13th	1,355.6	90.0
6.	21	CRG-AP x AZ-12-13	14th	1,343.2	91.0
7.	16	CRG-AP x AZ-6-13	18th	1,302.1	90.0
8.	6	CRG-AP x NK-2-13	20th	1,280.3	92.0
9.	15	CRG-AP x AZ-11-13	21st	1,275.3	90.0
10.	3	CRG-AP x AZ-8-13	22nd	1,266.4	90.0
Grand Mean*				**1,210.41**	**97.00**

*Mean stated is the grand mean for all 49 genotypes across all test locations

4.7 GGE biplot analysis for pod yield and stability of the 49 genotypes.

The GGE biplots in Figures 4.1, 4.2, and 4.3 were based on environment-focused singular value partitioning (SVP = 2) and genotype-focused singular value partitioning (SVP = 1) and they allowed visualization of the relationships among genotypes and among environments where desired. The principal component axis (PC1 and PC2) explained 55.28 % and 25.35 % of the total variation. Thus, these two axes accounted for 80.63 % of the total variation for pod yield (Figure 4.1). The results of the GGE biplot analysis are presented in three sections. Section one presents the results of "which won-where" which rank the best genotypes for each environment. The second section shows the performance of the genotypes based on mean and stability and the third section presents the results of the discriminating ability and representativeness of the test locations.

4.7.1 The "which-won-where" patterns

The polygon view of the GGE biplot (Figure 4.1) shows the best genotype in each environment. The "which-won-where" view of the GGE biplot is an effective visual tool used in multi-location analysis (Yan *et al*., 2007). It consists of an irregular polygon and lines drawn from the biplot origin, splitting the biplot into sectors. The vertex genotype is the genotype that gives the highest yield for each of the environment in which they lie. As depicted in Figure 4.1, Entry 49 (Otuhia) was the highest yielding genotype at Ejura (best genotype across all test environments); followed by Entry 27 (CRG-SH x NK-1-13), also emerging as the 4th best genotype across all test environments. Entry 43 (Oboshie) was the winner at Fumesua (5th best across environments); followed by Entry 34 (CRG-NP x NK-2-13), emerging as the 3rd best genotype across environments. No environment fell into the sectors where the following entries [Entry 11 (CRG-AP x NK-10-13), Entry 39 (CRG-AP x NK-12-13), Entry 23 (CRG-AP x NK-1-13), Entry 42 (CRG-SH x NK-2-13)], Entry 46 (Adepa), and Entry 22 (CRG-AP x NK-11-13)] were situated and these were the vertex genotypes, indicating that they were the lowest-yielding genotypes at all or some of the test locations.

Most of the genotypes evaluated in the study showed differential ranking in performance across the test locations. This is a strong indication of possible existence of crossover GEI and the existence of unstable genotypes, which suggests that a closer evaluation of the top genotypes according to their interactions with the studied environments is indeed necessary.

However, the following three (3) top genotypes exhibited similar yield performance at either two of the locations. Otuhia ranked as the best genotype across all test locations; 1st at Ejura (major season), and the 2nd best genotype at Fumesua (minor season) (Appendices 1 & 2). CRG-NP x NK-3-13 was the 2nd best genotype at Ejura (minor season), and 5th best genotype at Ejura (major season); and finally, CRG-SH x NK-1-13 was the 2nd best genotypes at Ejura (major season), and 5th best genotype at Ejura (minor season) (Appendix 2).

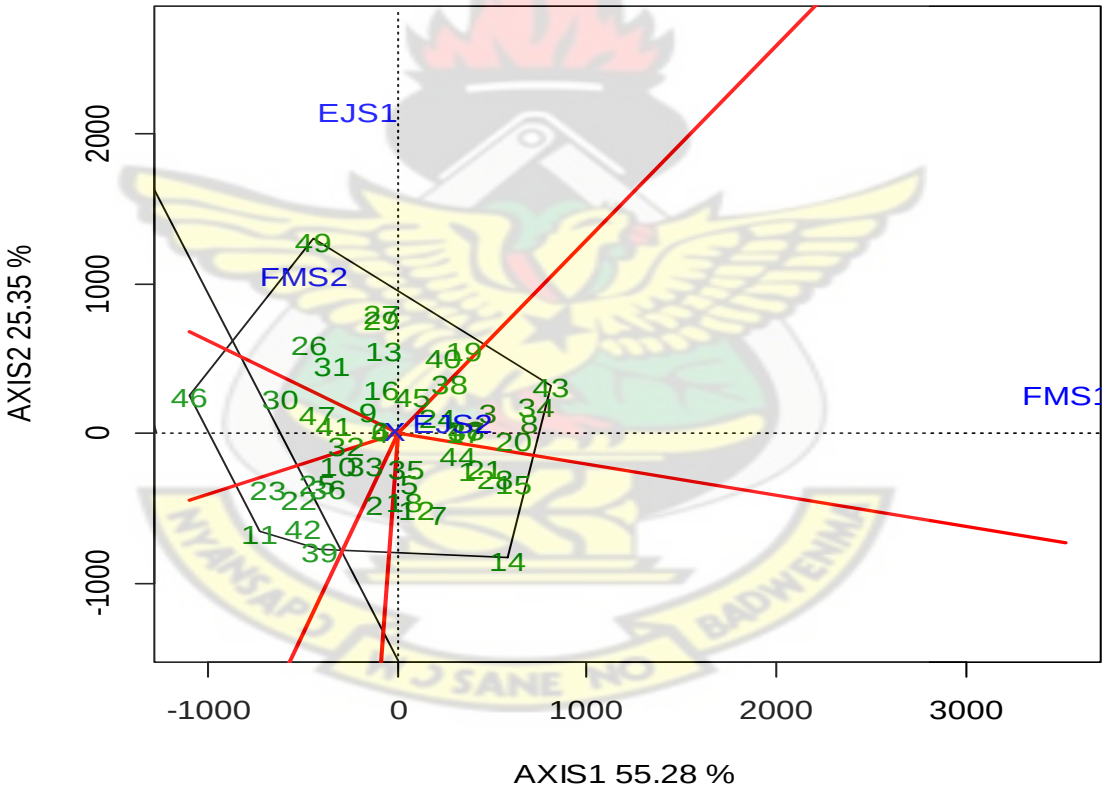

Figure 4.1: A 'which-won-where' or 'which was best for what' view of the GGE biplot of pod yield for 49 groundnut genotypes evaluated in two locations and two cropping seasons in Ghana.

4.7.2 Performance of genotypes based on means and stability

The biplot in Figure 4.2 is divided into four sectors by two lines passing through the origin. The slanted horizontal line with a small pointed arrow or x-axis is called the Average Environment Coordinate (AEC) abscissa; while the slanted vertical line or y-axis, is called the AEC ordinate. The y-axis or AEC ordinate separates the genotypes into two groups. The genotypes situated on the right side of the AEC ordinate (Figure 4.2) had pod yield higher than the average yield; while those on the left side of the AEC ordinate had yield lower than the average yield. The x-axis or AEC abscissa passes through the origin of the biplot and estimates the mean and stability of a genotype, while the small two-edged arrow on the AEC abscissa denotes an ideal genotype in terms of mean and stability estimation. A genotype is considered stable if it lies directly on the AEC abscissa; that is, having a zero projection onto the AEC abscissa. The farther the position of a genotype from the AEC abscissa, the less stable the genotype (Yan *et al*., 2000). Hence, entries 49 (Otuhia), 34 (CRG-NP x NK-2-13), 43 (Oboshie), 27 (CRG-SH x NK-1-13), 29 (Nkosour), 8 (CRG-AP x AZ-13-13), and 13 (Azivivi) were among the highest yielding genotypes across all test environments but less stable. From the view of the biplot, no ideal genotype could be identified. However, Entry 19 (CRG-AP x AZ-14-13) was the closest to the small two-edged arrow on the AEC abscissa (average-tester axis) and was considered the most representative of an ideal genotype in terms of stability (Figure 4.2). In addition to Entry 19 (CRG-AP x AZ-14-13), entries 40 (CRG-SH x AZ-6-13), 38 (CRG-AP x AZ-15-13), and 45 (Yenyawoso) were the most stable genotypes with an above average yield performance and had near zero projection onto the AEC abscissa. In contrast, entries 42 (CRG-SH x NK-2-13), 36 (CRG-SH x AZ-5-13), 33

(CRG-AP x NK-4-13) were below average (low yielding) but very stable genotypes (Figure 4.2).

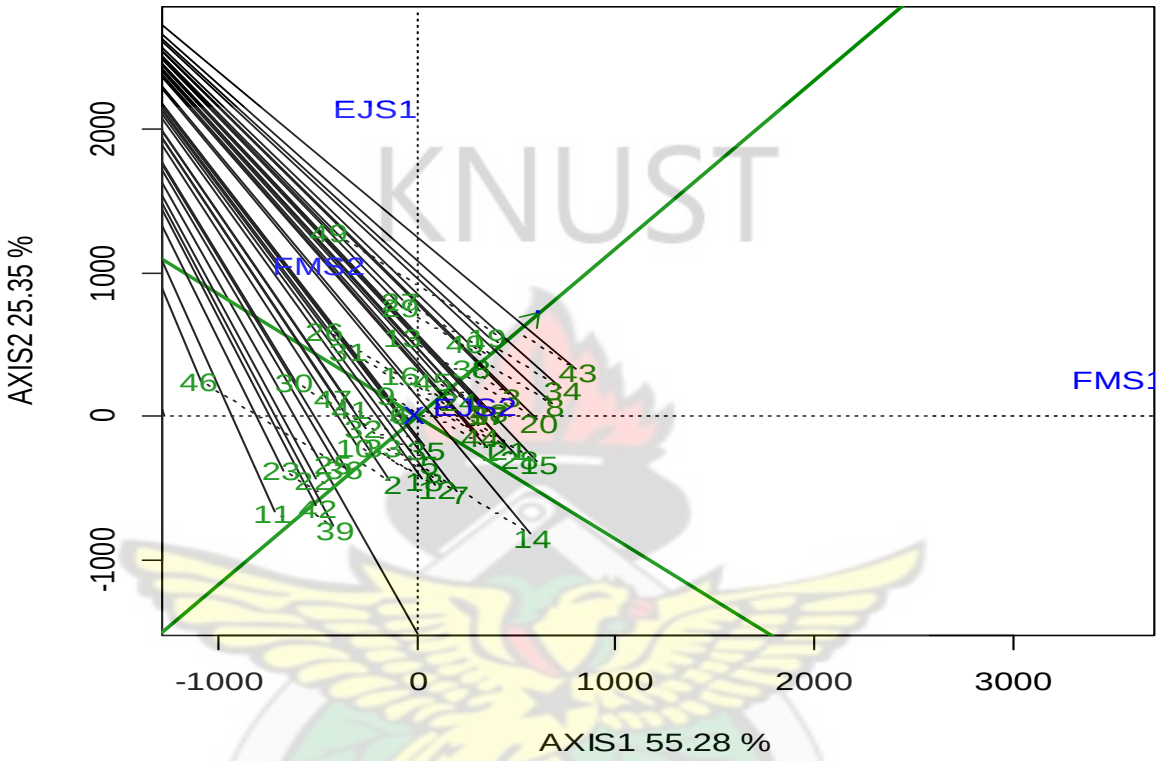

Figure 4.2: The 'mean vs. stability' view of the GGE biplot of pod yield for 49 groundnut genotypes evaluated in two locations and two cropping seasons in Ghana.

4.7.3 Discriminating ability and representativeness of the test locations

The biplot presented in Figure 4.3 provides graphical illustration of the discriminating ability and representativeness of the test environments. The dotted lines that connect the biplot origin and the markers for the environments are called environment vectors (Brar *et al*., 2010). The cosine of the angle between the vectors of two environments approximates the correlation coefficient between them. The smaller the angle between any two vectors, the more closely related they are. In addition, the length of the environment vector

measures the magnitude or its discriminating ability to assess the genotypes. Based on the method of Yan *et al*. (2010), vectors with shorter length are not strongly correlated with those with longer length and they may probably not be strongly correlated with one another either. Thus, FMS2 (Fumesua–minor season) has a medium length vector and signifies medium discriminating ability; while EJS2 (Ejura–minor season) with a shorter vector indicates very low ability in discriminating the genotypes. The two were therefore considered as distinct environments. In contrast, FMS1 (Fumesua–major season) and EJS1 (Ejura–major season) shared high discriminating abilities but were also considered as distinct environments because the angle between them was approximately 90º. However, Fumesua possessed more discriminating ability than Ejura as indicated by the length of its vector (Figure 4.3).

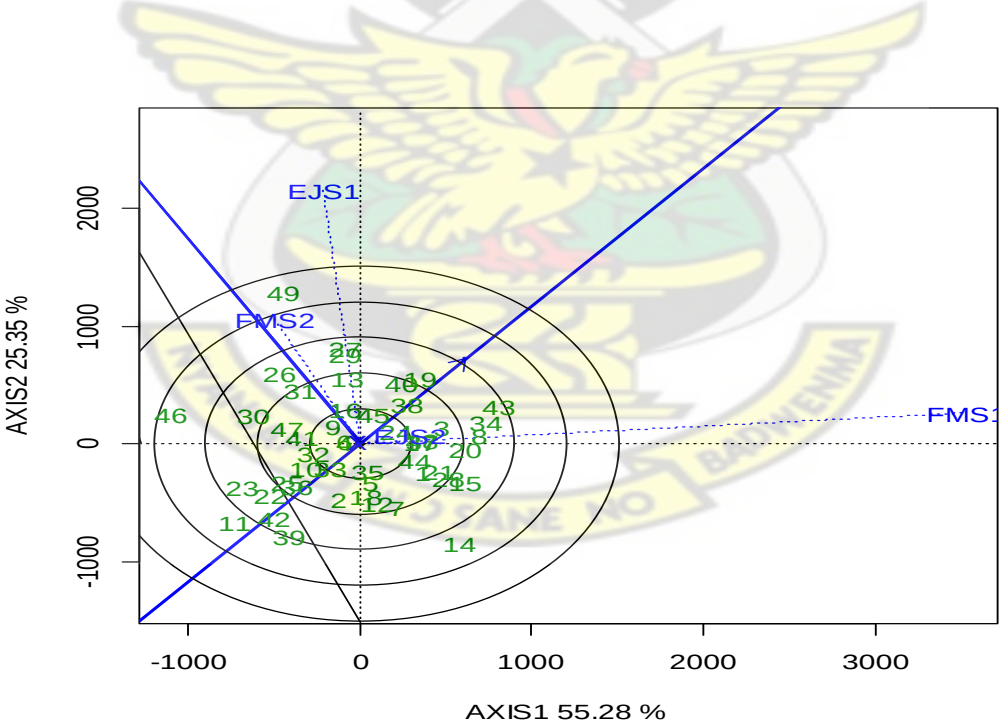

Figure 4.3: The biplot view showing the discriminating ability and representativeness of the test locations where the 49 groundnut genotypes were evaluated during the major and minor cropping seasons of Ghana.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Mean squares for pod yield for the two test environments and seasons

The observed significant differences among the genotypes at the different test locations and seasons for pod yield point to the genetic diversity of the genotypes used in the study. In addition, the observed differences in pod yield at the different test locations and seasons could be attributed to differences in soil conditions, rainfall patterns, temperatures and relative humidity. This was evident by the higher yield performance of genotypes at Fumesua during the two cropping seasons; a location characterized by sandy loam soils as compare to clay loam at Ejura. This is in agreement with De Waele and Swanevelder (2001) who reported that groundnut grows best in well-drained sandy loam soils, as light soil promotes easy pegs' penetration and development. The rainfall patterns during the major and minor seasons also contributed significantly to differences in yield at the two test locations. The high rainfall data recorded at Ejura during the major season resulted in excessive vegetative growth at the expense of reproductive growth, leading to lower pod yields of genotypes at that test location. These results are in line with findings of Wright *et al*. (2009) and Schilling and Gibbons (2002) who reported that excess soil moisture can trigger excessive vine growth in groundnut.

The low yields recorded during the minor cropping season at the two test locations also confirmed the results of Camberlin and Diop (1999) and Reddy *et al*. (2003) which indicated that low rainfall and prolonged dry spells during the growth periods is the main cause of low average yields in most of the regions of Asia and Africa. Brink and Belay

(2006) also stated that although groundnut is a drought tolerant crop and can withstand severe lack of water, yields can be generally reduced. Similar finding were reported by Gowda *et al*. (2009) and Prathima *et al*. (2011).

Differences in pod yields among test locations can also be attributed to the genetic composition of the genotypes used in the study. The diverse genetic backgrounds of the genotypes may help explain the observed genotypic variations. Uguru (2005) reported similar results stating that diverse agronomic characteristics are controlled by diverse genetic factors and so genotypes perform differently in a given location. Lonnquist (1967) also stated that yield is a quantitative trait influenced by G x E interaction.

Generally, higher yields were realized in Fumesua than Ejura during the two cropping seasons, which clearly indicate that Fumesua provides fairly optimum environmental conditions for the cultivation of groundnuts. The ANOVA results were in agreement with the results generated by the GGE biplot analysis, which also identified Fumesua as being the most ideal among the test locations.

5.2 Combined mean square analysis of genotypes for pod yield and other agronomic traits

Results from the combined mean square analysis for pod yield showed that location main effects were the key cause of variation, and accounted for 97.22% of the total variation; while genotypes and genotype by environment interaction (G x E) accounted for 0.58% and 0.61% of the total variation, respectively. Variations in yield performance among the genotypes at the different test locations and seasons could be attributed to differences in

soil conditions, rainfall patterns, temperatures and relative humidity. These observations are consistent with the findings of Badu-Apraku *et al*. (2003) and Mohammadi *et al*. (2009) who reported that the largest proportion of total variation in multi-environment trials is attributed to locations, whereas G and G × L sources of variation are relatively smaller. The significant mean square for location also revealed that genetic effects were influenced by the environments, which is a consequence of environmental diversity. Similar findings were reported by Lonnquist (1967) stating that quantitative traits, including pod yield are significantly influenced by environmental conditions.

The observed significant G x E interaction mean square for pod yield suggested that the locations in which the genotypes were tested consist of a number of special environments. This highlights the need to identify best performing genotypes for each test sites. From the results, genotypes CRG-NP x NK-2-13 and Otuhia exhibited superior yield performances at Fumesua and Ejura, respectively.

In addition to pod yield, the significant mean squares observed among locations for traits such as days to 50% flowering, days to maturity, plant height, number of branches per plant, number of pods per plant, pod yield per plant, 100 pod weight, number of seeds per pod and shelling percentage revealed that the genetic expressions of these parameters were influenced by the prevailing environmental conditions at the test locations during the two cropping seasons of 2014. The highly significant differences ($p<0.01$) due to genotypes that were observed among the entries for all nine traits points to the fact that the genotypes used in the study were developed from diverse genetic backgrounds. Similar observations have been cited by Zaman *et al*. (2011) and Thakur *et al.* (2013).

The significant mean squares detected for G x E interaction of days to 50% flowering, days to maturity, plant height, number of branches per plant, 100-pod weight, number of seeds per pod and shelling percentage revealed that these traits are unstable and were affected by differences in soil fertility, rainfall, relative humidity and temperatures. In contrast, the observed lack of significant mean squares for GEI of number of pods per plant and pod yield per plant indicated that these two traits were stable across the test locations and not affected by GEI. Zaman *et al.* (2011) indicated that selection based on such characters will be meaningful in predicting for pod yield in groundnut. Genotype x location interaction has, over the years, continued to cause setback for plant breeders which necessitate the need to carry out multi-location yield trials to identify and select high yielding genotypes with specific or wide adaptation to diverse agro-ecological zones.

5.3 Correlation between pod yield and traits of agronomic importance

Correlation is a measure of the degree of association between traits. It is therefore important for a breeder to understand that whenever two traits correlate positively, it indicates that selection for one trait can also mean selecting for the other trait (Acquaah, 2007). Nigam *et al*. (1991) reported that selection for yield and other quality traits (oil content, protein, diseases and pests resistance) has been the major basis for improving groundnut productivity in the world. Highly significant ($p<0.01$) and positive correlations were observed between pod yield and pod yield per plant (0.709), number of pods per plant (0.608), 100-pod weight (0.509), and shelling percentage (0.257); while the association between pod yield and number of branches per plant was significant ($p<0.05$) and weakly correlated. These traits could be used by plant breeders as pointers in forecasting yield. Similar observations were made by a number of researchers, stating that

pod yield was positively correlated with number and mass of seed plant^{-1} (Phadnis *et al*., 1973), 100 seed mass (Deshmukh *et al*., 1986), number of mature pods plant^{-1} (Alam *et al*., 1985; Liao *et al*., 1989). The present study also found that the number of pods per plant was positively correlated to pod yield per plant (0.854). This result is consistent with findings of Abraham (1990) who reported significant positive correlation of kernel yield with pods per plant, kernels per plant, 100-kernel weight and shelling percentage in 42 bunch type groundnut varieties. Shegro *et al.* (2013) noted similar observations in bambara groundnut.

The observed weakly negative and highly significant ($p<0.01$) correlations between pod yield and days to 50% flowering (-0.122) showed that pod yield cannot be improve through this trait. Days to maturity was weakly negative (-0.067) and not significant, indicating that selection based on this trait alone will lead to reduction in pod yield. This finding is in agreement with studies conducted by Meta and Monpara (2010) in groundnut.

5.4 Selection of superior genotypes by ranking method

The primary trait, pod yield is a complex character governed by a large number of cumulative duplicate, non-dominant genes and is quantitatively inherited (Dorairaj, 1962). The use of secondary traits in breeding significantly increases breeding progress as compared to selection for yield alone (Edmeades *et al*., 1997). Based on this, the selection of superior genotypes was based on two criteria, namely: yield performance only as the first criteria; while the second criteria considered both yield performance and early maturity. Based on yield performance only, Otuhia (a check) emerged as the best

performing genotype across all the test locations with a yield advantage of 2.70% over the best improved hybrid line, CRG-AP x AZ-14-13. Otuhia is however late maturing (106.0days); a trait of low preference among groundnut farmers in Ghana. In contrast, CRG-AP x AZ-14-13, which emerged as the second best performing genotype across all test locations, is early maturing (90.0days); a trait preferred by groundnut farmers. Overall, 15 genotypes (five checks and ten improved lines) were selected based on yield performance only, and ranged from 89.0 to 107.0 days to maturity; while ten improved hybrid lines were selected based on both yield performance and early maturity, and ranged from 89.0 to 92.0 days to maturity and these can be considered for onward release.

5.5 The GGE biplot analysis

The consistency of a genotype across several locations is a very important concern for plant breeders. It also highlights the ability of a genotype to perform better and determines its stability and ability to adapt to a wide range of locations (Fehr, 1987). Based on the biplot analysis of 'which won where', Entry 49 (Otuhia) was the highest yielding genotype at Ejura (best genotype across all test environments); followed by Entry 27 (CRG-SH x NK-1-13), also emerging as the 4th best genotype across all test environments. Entry 43 (Oboshie) was the winner at Fumesua (5th best across environments); followed by Entry 34 (CRG-NP x NK-2-13), emerging as the 3rd best genotype across all test environments. The latter result is contrary to the one generated from the SAS analysis for pod yield which identified Entry 34 (CRG-NP x NK-2-13) as the highest yielding genotype, although the two entries were statistically similar. The observed variation in rank between the two entries could be attributed to the method of scaling used in generating the biplot. Similar observation was reported by Yan (2002). In

addition, the biplot was unable to capture the performance of every entry due to the large number of entries used in the study. Similar findings have been reported by Yan and Hunt (2002), stating that a potential constraint of the biplot method is that it may not explain all of the variations. The biplot however identified some entries as vertex genotypes, indicating that they were the least yielding; the findings were in agreement with results generated from the SAS analysis. The entries include: Entry 11 (CRG-AP x NK-10-13), Entry 39 (CRG-AP x NK-12-13), Entry 23 (CRG-AP x NK-1-13), Entry 42 (CRG-SH x NK-2-13)], Entry 46 (Adepa), and Entry 22 (CRG-AP x NK-11-13).

In considering selection for broad adaptation, an ideal genotype should have both high mean performance and high stability within a mega-environment (Badu-Apraku *et al.*, 2011). Entry 19 (CRG-AP x AZ-14-13) was therefore identified as the most stable genotype. Other stable genotypes with an above average yield performance included entries 40 (CRG-SH x AZ-6-13), 38 (CRG-AP x AZ-15-13), and 45 (Yenyawoso). In contrast, entries 42 (CRG-SH x NK-2-13), 36 (CRG-SH x AZ-5-13), 33 (CRG-AP x NK-4-13) were below average but very stable. From the biplot view, entries 49 (Otuhia), 34 (CRG-NP x NK-2-13), 43 (Oboshie), 27 (CRG-SH x NK-1-13), 29 (Nkosour), 8 (CRG-AP x AZ-13-13), and 13 (Azivivi) were high yielding across all test environments but less stable.

Among the test locations, FMS1 (Fumesua–major season) and EJS1 (Ejura–major season) had longer environmental vectors, an indication of high discriminating abilities but were considered as distinct environments because the angle between them was approximately 90º. Fumesua had more discriminating ability and was considered the ideal test

environment than Ejura. This is in agreement with Yan and Rajcan (2002) who reported that an ideal test environment should effectively discriminate genotypes and represent their mega-environment.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

A total of 49 groundnut genotypes (39 newly improved lines and 10 varieties as checks) were evaluated across two locations during the major and minor seasons of 2014 to investigate the influence of G x E interaction on yield performance and stability. Most of the genotypes exhibited differential ranking in performance across the test locations, which suggests that evaluation of the top genotypes according to their interactions with the studied environments is indeed necessary. The combined mean square analysis for pod yield revealed that location main effects accounted for 97.22% of the total variation; while genotypes and genotype by environment interaction (G x E) accounted for 0.58% and 0.61% of the total variation, respectively. In addition to pod yield, the observed variations due to location effects for all nine traits studied revealed that the genetic expressions of these parameters were influenced by the prevailing environmental conditions. This indicates that environmental factors significantly influenced the performance of genotypes. Generally, higher yields were realized in Fumesua than Ejura during the study period, as confirmed by results from both SAS ANOVA and the GGE biplot analysis.

Positive correlations were observed between pod yield and pod yield per plant (0.709), number of pods per plant (0.608), 100-pod weight (0.509), and shelling percentage (0.257). These traits could be used by plant breeders as pointers in forecasting yield, and also justified the use of multi-trait selection method to identify the best genotypes in crop improvement programs.

Based on the overall yield performance, Otuhia (a check) emerged as the best performing genotype; but is however late maturing (106.0days). CRG-AP x AZ-14-13 was the second highest performer across all test locations; and emerged as the best genotype among the improved lines and also is early maturing (90.0days); a trait preferred by groundnut farmers in Ghana. Overall, ten improved hybrid lines were selected based on both yield performance and early maturity, and ranged from 89.0 to 92.0 days to maturity.

Finally, Entry 19 (CRG-AP x AZ-14-13), which emerged as the second highest performer across all test locations; was also identified as an ideal genotype in terms of high yielding ability and stability through the use of the GGE biplot analysis. Other stable and high yielding genotypes included entries 40 (CRG-SH x AZ-6-13), 38 (CRG-AP x AZ-15-13), and 45 (Yenyawoso). The GGE biplot analysis used in this study could assist breeders to make better decisions in variety selection and recommendation for release.

6.2 RECOMMENDATIONS

Based on the above results, it is recommended that supplementary test should be carried out on the ten high yielding and early maturing hybrid genotypes that were identified from the study in order to generate data to support on-farm testing for possible release in Ghana. Earliness and high yield performance are traits desired by groundnut farmers in Ghana. The availability of seeds of improved, early maturing and high yielding genotypes at affordable prices will not only be beneficial to resource poor farmers but will lead to increased groundnut production.

REFERENCES

Abraham, M. J. (1990). Correlation, Path and discriminant function analysis in Groundnut grown on P- deficient acidic soil. *Crop Improv*ement, 17(1)**:** 34-37.

Acquaah, G. (2007). Principles of plant genetics and breeding. Blackwell Publishing U. K., pp. 133.

Akubundu, I. O. (1987). Weed control in other food crops. In: Survey of weeds and management practices in peanut (*Arachi hypogaea* L.) in the Savanna ecology of Ghana. (Dzomeku, I. K., Abudulai, M., Brandenburg, R. L. and Jordan, D. L.). *Peanut science (2009).* 36: 165-173.

Aminifar, J., Mohsen, M. N. and Sirousmehr, A. (2013). Grain yield improvement of groundnut (Arachis hypogaea L.) under drought stress conditions. *International Journal of Agriculture and Crop Sciences*, 6(12): 819-824.

Alam, M. S., Begum, D. and Khair, A. B. M. A. (1985). Study of genetic parameters and character interrelationship in groundnut. *Bangladesh Journal of Agricultural Research*, 10 (2): 111-117.

Asibuo, J. Y., Akromah, R., Adu-Dapaah, H. and Safo-Katanka, O. (2008*a*). Evaluation of nutritional quality of groundnut (*Arachis hypogaea* L.) from Ghana. *African Journal of Food, Agriculture, Nutrition and Development*, 8(2): 133-150.

Asibuo, J. Y., Akromah, R., Safo Kantanka, O., Adu-Dapaah, H. K., Ohemeng-Dapaah and Agyeman A. (2008*b*). Inheritance of Fresh Seed Dormancy in Groundnut. *African Journal of Biotechnology*, 7:421-424.

Asibuo, J. Y., Akromah, R., Safo Kantanka, O., Adu-Dapaah, H. K., Ohemeng-Dapaah and Agyeman A. (2008*c*). Chemical Composition of groundnut (*Arachis hypogaea* L.) Landraces. *African Journal of Biotechnology*, 7(13):2203-2208.

Atuahene-Amankwa, G. and Hossain, M. A. (1990). Groundnut Production and Improvement in Ghana. First ICRISAT Regional Groundnut Meeting for West Africa; 13-16 Sept 1988; Niamey, Niger: ICRISAT.

Badu-Apraku, B., Abamu, F. J., Menkir, A., Fakorede, M. A. B., Obeng-Antwi, K. and The, C. (2003). Genotype by environment interactions in the regional early variety trials in West and Central Africa. *Maydica*, 48, 93-104.

Badu-Apraku, B., Akinwale, R. O., Menkir, A., Obeng-Antwi, K., Osuman, A. S., Coulibaly, N., Onyibe, J. E., Yallou, G. C., Abdullai, M. S. and Didjera, A. (2011). Use of GGE Biplot for Targeting Early Maturing Maize Cultivars to Mega-Environments in West Africa. *African Crop Science Journal*, 19(2): 79-96.

Balzarini, M., Bruno, C. and Arroyo, A. (2005). Analisis de ensayos agricolas multi-ambientales: Ejemplos con Info-Gen. Fac. de Cs. Agropec. U.N.C., Argentina. p. 141.

Banziger, M, Setim ela, P. S., Hodson, D. and Vivek, B. (2004). Breeding for improved drought tolerance in maize adapted to southern Africa. Proceedings of the 4th International *Crop Science* Congress, pp. 630-641.

Bear, J. E. and Bailey, W. K. (1973). Earliness of flower opening and potential for pod development in peanuts, *Arachis hypogaea* L. *Journal of the American Peanut Research and Education Association*, 5(1):26-31.

Becker, H. C. and Leon, J. (1988). Stability analysis in plant breeding. *Plant Breeding*, 101:1-23.

Bernardo, R. (2002). Genotype x environment interaction. In: Bernardo, R. (ed.) Breeding for quantitative traits in plants. Stemma Press. Woodbury, MN. pp. 147-171.

Beyene, Y., Mugo, S., Mutinda, C., Tefera, T., Karaya, H., Ajanga, S., Shuma, J., Tende, R. and Kega, V. (2011). Genotype by environment interactions and yield stability of stem borer resistant maize hybrids in Kenya. *African Journal of Biotechnology*, 10(23): 4752-4758.

Black, C. A. (1965). Methods of Soil Analysis . Part 2. Chemical and Microbiological properties. First edition. American society of Agronomy and Soil Science Society of America. Madison, Wisconsin, USA.

Bolhuis, G. G., Frinking, H. D., Leeuwaugh, I., Reno, R. G. and Staritsky, G. (1965). Observations on the opening of flowers, dehiscence of anthers and growth of pollen tubes in *Arachis hypogaea*. *Netherlands Journal of Agricultural Sciences*, 7:138-140.

Boote, K. J. and Ketring, D. L. (1990). Peanut. In: Irrigation of agricultural crops; Steward, B. A. and Nielson, D. R. (eds). ASA – CSSA – SSSA, Madison.

Brar, K. S., Singh, P., Mittal, V. P., Singh, P., Jakhar, M. L., Yadav, Y., Sharma, M. M., Shekhawat, U. S. and Kumar, C. (2010). GGE biplot analysis for visualization of mean performance and stability for seed yield in taramira at diverse locations in India. *Journal of Oilseed Brassica*, 1(2):66-74.

Bray, R. H. and Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science*, 59:39-45.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: Page, A. L., Miller, R. H. and Keeney, D. R. (eds). Methods of soil analysis Part 2. Chemical and microbiological properties. American Society of Agronomy and Soil Science of America, Madison, Wisconsin. Pp. 593-624.

Brink, M. and Belay, G. (2006). *Cereals and Pulses – PROTA*. Foundation and Buckhuys publishers/ CTA. Wageningen, Netherlands. Pp. 20-25.

Butron, A., Velasco, P., Orda´, S. A. and Malvar, R. (2004). Yield evaluation of maize cultivars across environments with different levels of pink stem borer infestation. *Crop Science*, 44: 741-747.

Camberlin, P. and Diop, M. (1999). Inter-Relationship between groundnut yield in Senegal, Inter-Annual rainfall variability and sea surface temperatures. *Theoretical and Applied Climatology*, 63 (3 & 4): 163-181.

Ceccarelli, S. (1989). Wide adaptation. How wide? *Euphytica*, 40, 197-205.

Chapman, R. S. and Carter, P. L. (2000). *Crop Production: Principles and Practices*. Surjeet Publications, Delhi, India.

Chiow, J. H. and Wynne, J. C. (1983). Heritabilities and genetic correlations for yield and quality traits of advanced generations in a cross of peanut. *Peanut Science*, 10: 13-17.

CGIAR (2004 – 2005). Research and Impact: Groundnut.

Coffelt, T. A. (1989). *Peanut.* In: Oil Crops of the World: Their Breeding and Utilization. Robbelen, G., Downey, R. K. and Ashri, A. (eds). Pp. 319-338. New York: McGraw-Hill Publishing company.

Crossa, J. (2012). From genotype × environment interaction to gene × environment interaction. *Current Genomics*, 13: 225-244.

Dabholkar, A. R. (1999). Elements of biometrical genetics. Concept Publishing Company. New Delhi, India.

Dakora, F. D., Abotinga, R. A., Mahama, Y. and Apaseku, J. (1987). Assessment of N_2-fixation in groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) and their relative contribution to a succeeding maize crop in Northern Ghana. *MIREEN Journal*, 3:389-399.

De Waele, D. and Swanevelder, C. J. (2001). Crop production in Tropical Africa. Goikink Graphic nv. Belgium. Pp. 747-753.

Deitos, A., Arnhold, E. and Miranda, G. V. (2006). Yield and combining ability of maize cultivars under different eco-geographic conditions. *Crop Breeding and Applied Biotechnology*, 6: 222-227.

Deshmukh, S. N., Basu, M. S. and Reddy, P. S. (1986). Genetic variability, character association and path coefficient of quantitative traits in Virginia bunch varieties of groundnut. *Indian Journal of Agricultural Science*, 56:816-821.

Dorairaj, M. S. (1962). Preliminary steps for the formulation of selection index for yield in groundnut. *Mandras Agricultural Journal*, 49: 12-27.

Edmeades, G. O., Bolaños, J. and Chapman, S. C. (1997). Value of secondary traits in selecting for drought tolerance in tropical maize. *In*: G. O. Edmeades, M. Bänziger, H. R. Mickelson, and C. B. Peña-Valdivia (eds.), Developing Drought and Low N Tolerant Maize. Proceedings of a Symposium, March 25-29, 1996, CIMMYT, El-Batán, Mexico, 222-234. Mexico.

Falconer, D. S. and Mackay, T. F. C. (1996). Introduction to quantitative genetics. 4th edition, Longman, New York, P.132-133.

FAO (2008). Crop Production Statistics from http://faostat.fao.org. Accessed 17 May 2014.

FAOSTAT (2011). Available at http://faostat.fao.org. Accessed 17 May 2014.

FAOSTAT (2013). Available At http://faostat.fao.org. Accessed 22 October 2014.

FAOSTAT (2014). Available at http://faostat.fao.org. Accessed 23 October 2014.

FAO/UNESCO Legend (1986). *Technical paper*. Soil classification and characterization, FAO, Rome.

Fehr, W. R. (1987). Principles of cultivar development. Macmillan publishing company. A Division of Macmillan Inc. New York, 1: 1-465.

Frimpong, A. (2002). Production guide on peanut and bambara peanut. In: Survey of weeds and management practices in peanut (*Arachis hypogaea* L.) in the Savanna ecology of Ghana. (Dzomeku, I. K., Abdulai, M., Brandenburg, R. L. and Jordan, D. L.) *Peanut Science (2009), 36(2): 165-173.*

Giller, K. E. and Wilson, K. J. (1991). Nitrogen fixation in tropical cropping systems. CAB International. Pp. 305.

Gowda, C. L. L., Serraj, R., Srinivasan, G., Chauhan, Y. S., Reddy, B. V. S., Rai, K. N., Nigam, S. N., Gaur, P. M., Reddy, L. J., Dwivedi, S. L., Upadhyaya, H. D., Zaidi, P. H., Rai, H. K., Maniselvan, P., Follkerstma, R., Nalini, M. (2009). Opportunities for improving crop water productivity through genetic enhancement of dryland crops. Rainfed Agriculture: Unlocking the Potential. CAB International, 2009.

Gregory, W. C. and Gregory, M. P. (1986). Groundnut; *Arachis hypogaea* in evolution of crop plants – (ed.) Simmonds. Longman, London. pp. 154 -155.

Gregory, W. C., Smith, B. W. and Yarbrough, J. A. (1951). Morphology, Genetics and Breeding in the Peanut. The unpredictable legume. *National Fertilizer Association*. Washington, DC. Pp. 28-85.

Gulp, T. W., Bailey, W. K. and Hammons, R. O. (1968). Natural hybridization of peanuts (*Arachis hypogaea*) in Virginia. *Crop Science*, 8:109-110.

Hammons, R. O. (1963). Artificial cross-pollination of the peanut with bee-collected pollen. *Crop Science*, 3:562-563.

Hammons, R. O. (1994**)**. The origin and history of groundnut. In: J. Smart (ed.), *The Groundnut crop: A scientific basis for improvement*. New York, Chapman Hall. Pp. 56-78.

Hassan, M. A. and Srivastava, D. P. (1966). Floral biology and pod development of peanut studied in India. *Journal of the Indian Botanical Society*, 45: 92-102.

Ibrahim, M., Florkowski, W. and Kolavalli, S. (2012). The determinants of farmer adoption of improved peanut varieties and their impact on farm income: Evidence from Northern Ghana. Presented at the *Agricultural and Applied Economics Association* Annual Meeting, Seattle, WA.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). (1978). Annual Report 1977-1978. Hyderabad, Andhra Pradesh, India: ICRISAT. Pp. 152.

ICRISAT. (1992). ICRISAT Groundnut: a global perspective. Available at http://www.icrisat.org. Accessed 3 November 2014.

Issa, A. B. (2009). Genotype by Environment Interaction and yield stability of maize hybrids evaluated in Ethiopia. *Thesis pdf*. Accessed 6 November 2014.

Jackson, P., Robertson, M., Cooper, M. and Hammer, G. L. (1998). The role of physiological understanding in Plant Breeding: From a breeding perspective. *Field Crops Research*, 49: 11-37.

Kandus, M. D., Almorza, R., Boggio, R. and Salerno, J. C. (2010). Statistical models for evaluating the genotype-environment interaction in maize (*Zea mays* L.).

Kang, M. S. (1996). Using genotype-by-environment interaction for crop cultivar development. *Advances in Agronomy*. 62: 199-252.

Kang, M. S. and Gorman, D. P. (1989). Genotype by environment interaction in maize. *Agronomy Journal*, 81(4): 662-664.

Kang, M. S., Balzarini, M. G. and Guerra, J. L. L. (2004). Genotype-by-environment interaction. *In* (A.M. Saxton ed.) Genetic Analysis of Complex Traits Using SAS. Cary, NC, USA.

Kang, M. S., Gorman, D. P. and Pham, H. N. (1991). Application of stability statistic to international maize yield trial. Baton Rouge LA, 70803-2110, USA. *Theory o*f A*pply Genetics*, 81:161-165.

Kavani, R. H., Golakia, P. R., Makne, V. G. and Madaria, R. B. (2004). Genetic variation and trait associations in Valencia groundnut (*Arachis Hypogaea* L.). In: *Proceedings of National symposium on enhancing productivity of groundnut for sustaining food and nutritional security*, NRCG, Junagadh.

Khan, M., Khalil, M. I. H. and Khan, M. A. (2004). Genetic divergence and association for yield and related traits in mash bean. *Sarhad Journal of Agriculture*, 20:555-61.

Kipkoech, A. K., Okiror, M. A., Okalebo, J. R. and Maritim, H. K. (2007). Production efficiency and economic potential of different soil fertility management strategies among groundnut farmers of Kenya. *Science World Journal* Vol 2 (no. 1).

Knauft, D. A., Norden, A. J. and Gorbet, D. W. (1987). Peanut. In: Principles of cultivar development (Fehr, W. R., Fehr, E. L., and Jessen, H. J. (eds.). Vol. 2. New York, USA: Macmillan. Pp. 346-384.

Knauft, D. A. and Wynne, J. C. (1995). Peanut breeding and genetics. *Advances in Agronomy*, 55:393-445.

Kotzamanidis, S. T., Stavropoulos, N. and Ipsilandis, P. (2006). Correlation Studies of 21 Traits in F_2 Generation of Groundnut (*Arachis hypogaea* L.). *Pakistan Journal of Biological Sciences*, 9: 929-934.

Liao, X. M., Zhang, L. H., Li, L. R. and Zheng, C. R. (1989). Correlation and partial correlation analyses of character of Spanish type groundnut varieties. *Oil Crops of China*, 1: 29-31.

Linnemann, A. R., Westphal, E. and Wessel, M. (1995). Photoperiod regulation of development and growth in bambara groundnut (*Vigna subterranea*). *Field Crops Research*, 40(1):39-47.

Litzenberger, S. C. (1976). Guide for field crops in the tropics and sub-tropics. *Peace Corps Programme and Training Journal*. Pp. 14-20.

Lonnquist, J. H. (1967). Mass selection for prolificacy in maize. *Der Zuchter*, 37: 185-187.

Malik, H. N., Malik, S. I., Hussain, M., Chughtai, S. U. R. and Javad, H. I. (2005). Genetic correlation among various quantitative characters in maize (*Zea mays L*.) hybrids. *Journal of Agriculture and Social Science*, 1: 262-265.

Marfo, K. O., Denker, N. N., Adu- Dapaah, H. K., Asafo Agyei, B., Marfo, K. A., Adjei, J. and Haleegoah, J. (1999). Groundnut Production in Ghana. Proceedings of a national workshop on groundnut aflatoxins, Kumasi, Ghana. Pp. 11-16.

Meta, H. R. and Monpara, B. A. (2010). Genetic variation and trait relationships in summer groundnut, (*Arachis hypogaea* L.). *Journal of Oilseeds Research*, 26:186-187.

MoFA (Ministry of Food and Agriculture), (2011). Agriculture in Ghana: Facts and Figures 2010. SRID, Accra, Ghana.

MoFA (Ministry of Food and Agriculture), (2013). Agriculture in Ghana: Facts and Figures 2012. www.mofa.gov.gh Accessed 14 May 2015.

Mohammadi, R., Amri, A., Haghparast, R., Sadeghzadeh, D., Armion, M. and Ahmadi, M. M. (2009). Pattern analysis of genotype-by-environment interaction for grain yield in durum wheat. *Journal of Agricultural Science*, Cambridge, 147, 537-545.

Moss, P. (1961). Limits of interference by Fe, Mn, Al and phosphate in the EDTA determination of Calcium in the presence of Mg using calcon-red as indicator. *Journal of the Science of Food and Agriculture*, 12: 30-34.

Muhammad, S. V. and Dorairaj, M. S. (1969). Flowering pattern and reproductive efficiency in bunch varieties of *Arachis hypogaea* L. *Madras Agricultural Journal*, 56(5):239-243.

Munns, R., Husain, S., Rivelli, A. R., James, R. A., Condon, A. G., Lindsay, M.P., Lagudah, E. S., Schachtman, D. P. and Hare, R. A. (2002). Avenues for increasing salt tolerance of crops, and the role of physiologically based selection traits. *Plant and Soil*, 247:93-105.

Mwariri, M., Kamidi, M., Wanjekeche, E., Omamo, B., Okumu, M. and Wanyonyirr, M. (2005). Grow and eat groundnut for more money and better health, Bulletin supported and funded by the Kenya Agricultural Research Institute and the Rockefeller Foundation.

Narasimhulu, R., Kenchanagordar, P. V. and Gowda, M. V. C. (2012). Study of genetic variability and correlation in selected groundnut genotypes. *International Journal of Applied Biology and Pharmaceutical Technology*, 3: 0976-4550.

Nelson, D. W. and Sommers, L. W. (1982). Total carbon and organic matter. In: Page, A. L., Miller, R. H. and Keeney, D. R. (eds.): Methods of soil analysis Part 2, 2nd ed. No. 9. American Society of Agronomy and Soil Science of America. Madison, Wisconsin, USA. Pp. 593-624.

Nigam, S. N., Dwivedi, S. L. and Gibbons, R. W. (1980). Groundnut breeding at ICRISAT. Pages 62-68 in proceedings of the International Workshop on Groundnut, 13-17 Oct 1980, ICRISAT Center, Patancheru, A.P. 502 324, India.

Nigam, S. N., Dwivedi, S. L. and Gibbons, R. W. (1991). Groundnut breeding: constraints, achievements and future possibilities. *Plant Breeding Abstracts*, 61: 1127-1136.

Nigam, S. N., Vasudeva Rao, M. J. and Gibbons, R. W. (1983). Utilization of natural hybrids in the improvement of groundnuts (*Arachis hypogaea* L.). *Experimental Agriculture*, 19:355-359.

Nigam, S. N., Vasudeva Rao, M. J. and Gibbons, R. W. (1990). Artificial hybridization in groundnut. *Information Bulletin* no. 29. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Norden, A. J. (1973). Breeding of cultivated peanuts. Pages 175-208 in Peanut – culture and uses (Pattee, H. E. and Young, C. T., eds.). Yoakum, Texas, USA: *American Peanut Research and Education Association.*

Norden, A. J. (1980). Peanut. Pages 443-456 *in* Hybridization of crop plants. (Fehr, W. R. and Hadley, H. H., eds.). Madison, Wisconsin, USA: American Society of Agronomy and Crop Science Society of America.

Nutsugah, S. K., Oti-Boateng, C., Tsigbey, F. K. and Brandenburg, R. L. (2007). Assessment of yield losses due to early and late leaf spots of groundnut (*Arachis hypogaea* L.) *Ghana Journal of Agriculture Science,* 40(1): 21-26.

Ntare, B. R., Diallo, A. T., Ndjeunga, J. and Waliyar, F. (2008). Groundnut Seed production Manual, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Pp. 8-20.

Odewale, J. O., Collins, A., Ataga, C. D., Odiowaya, G., Ahanor, M. J., Edokpayi, A. A., Okoye, M. N. and Uwadiae, E. O. (2012). Comparison of yield and stability assessment of five coconut (*Cocos nucifera* L.) varieties in a lethal yellow disease (LYD) endemic field over nine different environments. *World Journal of Agricultural Sciences,* 8 (3): 229-233: 1817-3047.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (1993). Laboratory methods of soil and plant analysis: A working manual. Tropical Soil Biology and Fertility. Soil Science Society of East Africa. Technical Publication No.1. Nairobi, Kenya. P. 88.

Page, W. W., Busolo-Bulafu, C. M., Vander Merwe, P. J. A. and Chancellor, T. C. B. (2002). Groundnut Manual for Uganda: Recommended Groundnut Production Practices for Smallholder Farmers in Uganda. Chatham, UK: Natural Resources Institute.

Patel, J. D., Desai, N. C., Kodappully, V. C. and Vaghela, K. O. (2009). Genetic variability, correlation and path analysis in moth bean. *GAU Research Journal*, 34(2): 83-87.

Patterson, R. M., Weaver, D. B. and Thurlow, D. L. (1983). Stability parameters of soybean cultivars in maturity groups VI, VII, and VIII. *Crop Science*, 23:569-571.

Peanut CRSP, (1990). The Peanut CRSP: Improving global production and use of peanut. Research Summary, 1982-1990. University of Georgia, Griffin. p. 16.

Peipho, H. P. and Mohring, J. (2005). Best Linear unbiased prediction of cultivar effects for subdivided target regions. *Crop Science*, 45: 1151-1159.

Phadnis, B. A., Ekbote, A. P. and Manker, A. R. (1973). Correlation studies in some metrical characters in groundnut (*Arachis hypogaea* L.). *JNKVV Research Journal*, 7: 68-72.

Prasad, P. V. V., Craufurd, P. Q., Summerfield, R. J. and Wheeler, T. R. (1998). Sensitivity of fruit set to heat stress in groundnut. *Journal of Experimental Botany, 40: 30*.

Prasad, P. V. V., Craufurd, P. Q. and Summerfield, R. J. (1999). Sensitivity of peanut to timing of heat stress during reproductive development. *Crop Science*, 39: 1352-1357.

Prathima, T., Yellamanda Reddy, T., Murali Krishna, T., Devaki, K., Sudhakar, P., Sarala, N. V., Muneendra Babu, A., Naga Madhuri, K. V. (2011). Validation of peanut growth model for moisture stress effects on rainfed groundnut in major crop growing areas of Andhra Pradesh, India - A critical review. *International Journal of Applied Biology and Pharmaceutical Technology*, 2(4) 482-509.

Purseglove, J. W. (1975). Tropical crops. Monocotyledons Vol. 1 and 2 combined. Longmanns.

Raemekers, R. H. (2001). Crop Production in Tropical Africa, DGIC, Brussels, Belgium. Pp. 205-221.

Ramagosa, I., Fox, P. N., Garcia Del Moral, L. F., Ramos, J. M., Roca De Togores, F. and Molina Cano, J. L. (1993). Integration of statistical and physiological analyses of adaptation of near-isogenic barley lines. *Theory of Apply Genetics, 86*, 822-826.

Ramanatha Rao, V. (1988). Botany. Pages 24-64 *in* Groundnut (Reddy, P.S., ed.). New Delhi, India: Indian Council of Agricultural Research.

Reddi, M. V., Reddy, K. R., Reddy, K. H. P. and Rao, J. A. (1991). Heritability, genetic advance and character association in groundnut over three environments. *Journal of Maharashtra Agricultural University*, 16(3)**:** 383-385.

Reddy, A. A. (2009). Policy Options for India's Edible Oil Complex. *Economic and Political Weekly*, 44(4):22-24.

Reddy, A. A. and Bantilan, M. C. S. (2011). Competitiveness and Efficiency in Groundnut Oil Sector of India Policy Brief, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India. p. 14.

Reddy, A. A. and Bantilan, M. C. S. (2012). Competitiveness and technical efficiency: Determinants in the groundnut oil sector of India. *Food Policy*, 37(3):255-263.

Reddy, A. A., Radhika, C. H. R. and Reddy, G. P. (2011). "Policy Options for Edible Oil Complex in India under WTO Regime." *Journal of Rural Development*, 30(1):11-24.

Reddy, E. Y., Reddy, V. R. and Anbumozhi, V. (2003). Physiological responses of groundnut (*Arachis hypogaea* L.) to drought stress and its amelioration: a critical review. *Plant Growth Regulation*, 41: 75-88.

Reddy, L. J. and Kaul, A. K. (1986). Status and prospects of groundnut in Bangladesh. Bangla Argil Press, Dhaka. pp. 1-51.

SAS Institute. (2002). Statistical Analysis Software (SAS) user's guide Version 9.2. SAS Institute, Inc., Cary, NC, USA.

Sastri, D. C. and Moss, J. P. (1982). Effects of growth regulators on incompatible crosses in the genus *Arachis* L. *Journal of Experimental Botany*, 33: 1293-1301.

Savage, G. P. and Keenan, J. I. (1994). *The composition and nutritive value of groundnut kernel*. Pages 173-213 in: The groundnut crop. A scientific basis for improvement. J. Smart (ed). Chapman and Hall, London.

Schilling, R. and Gibbon, R. (2002). *Groundnut*. Macmillan Education Limited, London and Oxford. pp. 1-93.

Shah, M. A., Rahim, J., Hassan, S., Rashid, A. and Jan, H. (1993). Screening of mungbean genotypes for genetic parameters and protein content. *Sarhad Journal of Agriculture*, 9(4):317-321.

Sharma, V. K. and Varshney, S. K. (1995). Analysis of harvest index in groundnut. *Journal of Oilseed Research*, 12(2):171-175.

Shegro, A., Jansen van Rensburg, W. S. and Adebola, P. O. (2013). Assessment of genetic variability in Bambara groundnut (*Vigna subterranean* L. Verdc.) using morphological quantitative traits. *Academia Journal of Agricultural Research*, 1(3): 045-051.

Shilman, F., Brand, Y., Brand, A., Hedvat, I. and Hovav, R. (2011). Identification and Molecular Characterization of Homeologous Δ9-Stearoyl Acyl Carrier Protein Desaturase 3 Genes from the Allotetraploid Peanut (*Arachis hypogaea* L.). *Plant Molecular Biology Reporter*, 29, 232-241.

Simmonds, N. W. (1962). Variability in crop plants, its use and conservation. *Biological Review*, 37: 422-465.

Sivakumar, M. V. K., Maidouka, A. and Stern, R. D. (1993). Agro-climatology of West Africa: Niger. *Information Bulleting* No. 5. Patancheru, ICRISAT.

Smith, A. B., Cullis, B. R. and Thompson, R. (2005). The analysis of crop cultivar breeding and evaluation trials: an overview of current mixed model approaches. *Journal of Agricultural Science*, 143: 449-462.

Smith, B. W. (1954). *Arachis hypogaea,* Reproductive efficiency. *American Journal of Botany*, 41, 607-616.

Souza, L. V., Miranda, G. V., Galvão, J. C. C., Eckert, F. R., Mantovani, E. E., Lima, R. O. and Guimarães, L. J. M. (2008). Genetic control of grain yield and nitrogen use efficiency in tropical maize. *Pesquisa Agropecuária Brasileira*, 43: 1517-1523.

Squire, G. R., Connolly, H., Crawford, J., Collinson, S. T. and Sesay, A. (1996). Linking vegetative and reproductive trait variability in landraces of Bambara groundnut. In: Azam-Ali, S. N. (Ed). Proceedings of the International Bambara groundnut symposium, University of Nottingham, U. K. pp. 201-213.

Suzuki, D., Griffiths, A. and Lewontin, R. (1981). An introduction to genetic analysis. W. H. Freeman and Company. San Francisco, USA.

Taru, V. B., Kyagya, I. Z., Mshelia, S. I. and Adebayo, E. F. (2008). Economic Efficiency of Resource Use in Groundnut Production in Adamawa State of Nigeria. *World Journal of Agricultural Sciences*. 4: 896-900.

Thakur, S. B., Ghimire, S. K., Shrestha, S. M., Chaudhary, N. K. and Mishra, B. (2013). Variability in Groundnut Genotypes for Tolerance to Drought. *Nepal Journal of Science and Technology*, 14(1): 41-50.

Tweneboah, C. K. (2000). Modern Agriculture in the Tropics with special reference to Ghana. Co-Wood Publishers, Accra, Ghana. pp. 189-190.

Tsigbey, F. K., Brandenburg, R. L. and Clottey, V. A. (2003). Peanut Production Methods in Northern Ghana and some Disease Perspectives. *Online Journal of Agronomy*, 34:36-47.

Uguru, M. I. (2005). Crop Genetics and Breeding (Revised). Epharata Press, Nsukka, Enugu State, Nigeria. P. 113.

Vargas, M., Crossa, J., Van Eeuwijk, F. A., Ramirez, M. E. and Sayre, K. (1999). Using AMMI, factorial regression and partial least squares regression models for interpreting genotype by environment interaction. *Crop Science*, 39: 955-967.

Vasanthi, R. P., Naidu, P. H. and Rao, A. S. (1998). Genetic variability and correlation of yield, component traits and foliar disease resistance in groundnut. *Journal of Oilseed Research*, 15: 345-347.

Weiss, E. A. (2000). *Oilseed crops*. Blackwell Science. London.

Wright, D. L., Tillman, B., Jowers, E., Marios, J., Ferell, J. A., Katsvairo, T. and Whitty, E. B. (2009). Management and Cultural Practices for Peanuts. Publication # SS–AGR–74 (www.edis.ifas.ufl.edu. Accessed 29 May 2014).

Yan, W. (2001). GGE Biplot - A windows application for graphical analysis of multi-environment trial data and other types of two-way data. *Agronomy Journal*, 93:1111-1118.

Yan, W. (2002). Singular-value partitioning in biplot analysis of multienvironment trial data. *Agronomy Journal*, 94:990-996.

Yan, W., Fregeau-Reid, J., Pageau, D., Martin, R., Mitchellfetch, J., Etienne, M., Rowsell, J., Scott, P., Price, M., Dehaan, B., Cummiskey, A., Lajeunesse, J., Durand, J. and Sparry, E. (2010). Identifying essential test locations for oat breeding in Eastern Canada. *Crop Science*, 50: 504-515.

Yan, W. and Hunt, L. A. (1998). Genoytype by environment interaction and crop yield. *Plant Breeding*, 16:135-178.

Yan, W. and Hunt, L. A. (2002). Biplot analysis of diallel data. *Crop Science*, 41:19-25.

Yan, W. and Kang, M. S. (2003). GGE bi-plot analysis: A graphical tool for breeders, geneticists, and agronomists. 1st Edition, CRC Press, LLC., Boca Raton, Florida, USA. Pp. 271.

Yan, W. and Rajcan, I. (2002). Biplot evaluation of test locations and trait relations for breeding superior soybean cultivars in Ontario. *Crop Science*, Volume 42, pp. 11-20.

Yan, W., Hunt, L. A., Sheng, Q. and Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Science,* 40: 597- 605.

Yan, W., Kang, M. S., Ma, B., Woods, S. and Cornelius, P. L. (2007). GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science,* 47: 643-655.

Yau, S. (1995). Regression and AMMI analyses of genotype x environment interactions: An empirical comparison. *Agronomy Journal,* 87: 121-126.

Yayeh, Z. and Bosland, P. W. (2000). Evaluation of genotype, environment and genotype-by-environment interaction for capsaicinoids in *Capsicum annum* L. *Euphytical,* 111: 185-190.

Zaman, M. A., Tuhina-Khatun, M., Ullah, M. Z., Moniruzzamn, M. and Alam, K. H. (2011). Genetic variability and path analysis of groundnut (*Arachis hypogaea* L.). *The Agriculturists,* 9: 29-36.

Zivanovic, T., Vracarevic, M., Krstanovic, S. and Surlan-Momirovic, G. (2004). Selection of uniformity and yield stability in maize. Institute of biological sciences, *Journal of Agricultural Sciences,* Vol. 49, No 1: 117-130.

APPENDICES

Appendix 1: List of 49 groundnut genotypes with yield performance (Kg ha^{-1}) at Fumesua during the major and minor seasons of 2014

Fumesua						
		Major Season			Minor Season	
Entry No.	Genotypes	Rank	Pod Yield (Kg/Ha)		Rank	Pod Yield (Kg/Ha)
1	CRG-SH x AZ-3-13	8th	2,612.5		22nd	1,336.8
2	CRG-AP x AZ-1-13	30th	1,981.2		34th	1,112.5
3	CRG-AP x AZ-8-13	3rd	2,818.9		36th	1,105.1
4	CRG-SH x AZ-7-13	17th	2,307.7		41st	1,043.1
5	CRG-SH x AZ-4-13	25th	2,121.2		35th	1,106.4
6	CRG-AP x NK-2-13	12th	2,494.0		7th	1,607.4
7	CRG-SH x AZ-2-13	24th	2,123.9		33rd	1,166.8
8	CRG-AP x AZ-13-13	4th	2,784.6		25th	1,278.1
9	CRG-AP x AZ-9-13	29th	1,986.0		6th	1,610.5
10	CRG-AP x NK-3-13	31st	1,968.3		3rd	1,833.6
11	CRG-AP x NK-10-13	45th	1,313.6		27th	1,264.9
12	CRG-NP x NK-7-13	21st	2,161.8		20th	1,338.4
13	Azivivi	32nd	1,957.0		26th	1,270.5
14	Shitaochi-Local	10th	2,509.9		49th	757.7*
15	CRG-AP x AZ-11-13	6th	2,708.9		31st	1,185.6
16	CRG-AP x AZ-6-13	22nd	2,145.6		11th	1,438.7
17	CRG-AP x AZ-3-13	9th	2,549.5		8th	1,553.5
18	CRG-AP x NK-6-13	20th	2,204.5		38th	1,063.1
19	CRG-AP x AZ-14-13	27th	2,030.8		23rd	1,324.0
20	CRG-AP x AZ-2-13	2nd	2,871.4		18th	1,385.5
21	CRG-AP x AZ-12-13	19th	2,283.8		28th	1,245.0
22	CRG-AP x NK-11-13	39th	1,522.4		4th	1,826.3
23	CRG-AP x NK-1-13	47th	1,175.5		46th	947.6
24	CRG-AP x NK-8-13	16th	2,334.4		48th	906.4
25	CRG-AP x AZ-7-13	46th	1,231.6		12th	1,436.3
26	CRG-NP x NK-3-13	48th	1,163.2		13th	1,434.9
27	CRG-SH x NK-1-13	34th	1,914.3		10th	1,493.1
28	CRG-AP x AZ-10-13	14th	2,392.2		42nd	1,042.1

Appendix 1 continued

29	Nkosour	28th	2,029.6		9th	1,516.9
30	CRG-SH x AZ-1-13	38th	1,525.2		5th	1,719.8
31	CRG-AP x NK-9-13	41st	1,480.4		1st	2,097.7**
32	CRG-AP x NK-5-13	37th	1,613.6		44th	1,011.1
33	CRG-AP x NK-4-13	44th	1,424.0		32nd	1,180.9
34	CRG-NP x NK-2-13	1st	3,026.0**		16th	1,413.5
35	CRG-AP x AZ-16-13	26th	2,069.9		30th	1,198.3
36	CRG-SH x AZ-5-13	35th	1,874.2		21st	1,337.3
37	CRG-AP x AZ-4-13	13th	2,419.8		37th	1,101.5
38	CRG-AP x AZ-15-13	11th	2,500.6		14th	1,429.7
39	CRG-AP x NK-12-13	40th	1,519.3		45th	971.1
40	CRG-SH x AZ-6-13	18th	2,290.0		24th	1,317.3
41	CRG-AP x AZ-5-13	23rd	2,126.8		17th	1,389.4
42	CRG-SH x NK-2-13	42nd	1,463.2		39th	1,052.3
43	Oboshie	5th	2,712.9		43rd	1,028.1
44	Obolo	15th	2,347.0		19th	1,369.1
45	Yenyawoso	33rd	1,938.4		47th	926.8
46	Adepa	49th	721.1*		29th	1,229.5
47	Jenkaar	43rd	1,435.4		40th	1,051.7
48	Kumawu-Local	7th	2,651.6		15th	1,428.5
49	Otuhia	36th	1,620.1		2nd	1,856.2
Grand mean			**2,050.20**			**1,300.80**
LSD (0.05)			975.90			558.50
CV (%)			26.6			24.0

** Highest; * Least

Appendix 2: List of 49 groundnut genotypes with yield performance (Kg ha^{-1}) at Ejura during the major and minor seasons of 2014

Ejura						
		Major Season			Minor Season	
Entry No.	**Genotypes**	**Rank**	**Pod Yield (Kg/Ha)**		**Rank**	**Pod Yield (Kg/Ha)**
1	CRG-SH x AZ-3-13	35th	484.2		18th	801.6
2	CRG-AP x AZ-1-13	33rd	493.2		43rd	586.4
3	CRG-AP x AZ-8-13	28th	684.4		38th	633.7
4	CRG-SH x AZ-7-13	15th	860.1		34th	678.2
5	CRG-SH x AZ-4-13	42nd	405.3		1st	1,114.7**
6	CRG-AP x NK-2-13	23rd	759.5		35th	671.5
7	CRG-SH x AZ-2-13	46th	347.9		33rd	701.4
8	CRG-AP x AZ-13-13	20th	812.5		16th	813.1
9	CRG-AP x AZ-9-13	14th	879.7		32nd	705.1
10	CRG-AP x NK-3-13	40th	429.2		47th	550.1
11	CRG-AP x NK-10-13	48th	285.8		49th	434.7*
12	CRG-NP x NK-7-13	49th	249.3*		29th	718.2
13	Azivivi	4th	1,277.3		13th	823.0
14	Shitaochi-Local	43rd	403.7		23rd	754.3
15	CRG-AP x AZ-11-13	34th	486.2		12th	832.3
16	CRG-AP x AZ-6-13	12th	938.4		11th	848.0
17	CRG-AP x AZ-3-13	38th	459.9		15th	818.0
18	CRG-AP x NK-6-13	45th	369.2		28th	725.1
19	CRG-AP x AZ-14-13	11th	981.5		3rd	989.6
20	CRG-AP x AZ-2-13	32nd	498.6		39th	628.0
21	CRG-AP x AZ-12-13	30th	598.4		4th	943.4
22	CRG-AP x NK-11-13	44th	392.2		20th	785.1
23	CRG-AP x NK-1-13	24th	752.8		14th	818.5
24	CRG-AP x NK-8-13	9th	1,035.4		37th	641.7
25	CRG-AP x AZ-7-13	37th	460.2		6th	922.0

Appendix 2 continued

26	CRG-NP x NK-3-13	5th	1,247.0		2nd	1,047.1
27	CRG-SH x NK-1-13	2nd	1,483.3		5th	927.6
28	CRG-AP x AZ-10-13	25th	742.5		40th	625.2
29	Nkosour	3rd	1,440.0		36th	656.1
30	CRG-SH x AZ-1-13	26th	737.2		45th	580.3
31	CRG-AP x NK-9-13	19th	826.9		30th	716.7
32	CRG-AP x NK-5-13	13th	922.5		44th	584.2
33	CRG-AP x NK-4-13	29th	684.3		9th	858.6
34	CRG-NP x NK-2-13	18th	843.5		10th	853.0
35	CRG-AP x AZ-16-13	10th	1,017.7		27th	728.4
36	CRG-SH x AZ-5-13	31st	509.9		7th	905.4
37	CRG-AP x AZ-4-13	21st	787.7		31st	713.1
38	CRG-AP x AZ-15-13	27th	688.8		22nd	767.5
39	CRG-AP x NK-12-13	47th	286.5		42nd	602.0
40	CRG-SH x AZ-6-13	6th	1,223.2		24th	753.4
41	CRG-AP x AZ-5-13	16th	859.5		41st	616.2
42	CRG-SH x NK-2-13	39th	429.7		8th	896.3
43	Oboshie	17th	845.6		19th	793.0
44	Obolo	41st	423.8		17th	804.1
45	Yenyawoso	8th	1,040.6		25th	740.1
46	Adepa	7th	1,217.5		48th	500.5
47	Jenkaar	22nd	776.0		46th	558.9
48	Kumawu-Local	36th	466.0		21st	780.6
49	Otuhia	1st	1,672.8**		26th	738.4
Grand mean			**745.20**			**748.70**
LSD (0.05)			535.31			333.94
CV (%)			40.1			24.9

** Highest; * Least

Appendix 3: Combined mean performance for pod yield (Kg ha^{-1}), days to maturity and days to 50% flowering of the 49 groundnut genotypes

No.	Entry No.	Genotypes	Yield Rank	Yield (Kg/Ha)	Days to Maturity	Days to 50% Flowering
1	49	Otuhia	1st	1,530.7**	106.0	32.0
2	19	CRG-AP x AZ-14-13	2nd	1,490.5	90.0	28.3
3	34	CRG-NP x NK-2-13	3rd	1,486.7	104.0	27.8
4	27	CRG-SH x NK-1-13	4th	1,445.8	105.0	31.7
5	43	Oboshie	5th	1,441.1	106.0	31.5
6	40	CRG-SH x AZ-6-13	6th	1,408.6	104.0	28.3
7	17	CRG-AP x AZ-3-13	7th	1,390.4	89.0*	27.3*
8	29	Nkosour	8th	1,375.3	106.0	32.1
9	20	CRG-AP x AZ-2-13	9th	1,372.7	90.0	28.5
10	48	Kumawu-Local	10th	1,372.5	92.0	28.1
11	31	CRG-AP x NK-9-13	11th	1,361.7	104.0	27.8
12	8	CRG-AP x AZ-13-13	12th	1,359.6	90.0	28.6
13	38	CRG-AP x AZ-15-13	13th	1,355.6	90.0	28.8
14	21	CRG-AP x AZ-12-13	14th	1,343.2	91.0	28.5
15	44	Obolo	15th	1,322.4	107.0**	31.4
16	26	CRG-NP x NK-3-13	16th	1,312.5	104.0	32.8
17	13	Azivivi	17th	1,306.5	105.0	31.9
18	16	CRG-AP x AZ-6-13	18th	1,302.1	90.0	29.3
19	45	Yenyawoso	19th	1,282.0	101.0	27.8
20	6	CRG-AP x NK-2-13	20th	1,280.3	92.0	28.7
21	15	CRG-AP x AZ-11-13	21st	1,275.3	90.0	29.2
22	3	CRG-AP x AZ-8-13	22nd	1,266.4	90.0	28.4
23	37	CRG-AP x AZ-4-13	23rd	1,264.3	91.0	28.1
24	1	CRG-SH x AZ-3-13	24th	1,258.2	91.0	29.6
25	35	CRG-AP x AZ-16-13	25th	1,218.4	92.0	29.6
26	5	CRG-SH x AZ-4-13	26th	1,213.2	91.0	27.7
27	24	CRG-AP x NK-8-13	27th	1,208.3	103.0	29.4

Appendix 3 continued

28	9	CRG-AP x AZ-9-13	28th	1,205.2	90.0	29.6
29	28	CRG-AP x AZ-10-13	29th	1,188.7	90.0	29.8
30	33	CRG-AP x NK-4-13	30th	1,139.7	91.0	28.5
31	4	CRG-SH x AZ-7-13	31st	1,129.7	101.0	27.7
32	41	CRG-AP x AZ-5-13	32nd	1,125.7	91.0	29.5
33	7	CRG-SH x AZ-2-13	33rd	1,120.2	91.0	28.9
34	10	CRG-AP x NK-3-13	34th	1,102.6	90.0	29.2
35	12	CRG-NP x NK-7-13	35th	1,100.5	91.0	27.5
36	30	CRG-SH x AZ-1-13	36th	1,098.6	104.0	31.4
37	14	Shitaochi-Local	37th	1,095.7	91.0	28.1
38	18	CRG-AP x NK-6-13	38th	1,093.1	103.0	29.1
39	25	CRG-AP x AZ-7-13	39th	1,068.8	90.0	30.8
40	32	CRG-AP x NK-5-13	40th	1,068.4	91.0	28.3
41	36	CRG-SH x AZ-5-13	41st	1,052.2	91.0	28.8
42	47	Jenkaar	42nd	1,043.0	106.0	33.3**
43	22	CRG-AP x NK-11-13	43rd	1,031.3	96.0	28.8
44	2	CRG-AP x AZ-1-13	44th	1,016.9	90.0	29.9
45	46	Adepa	45th	974.1	106.0	32.9
46	42	CRG-SH x NK-2-13	46th	938.4	106.0	28.8
47	23	CRG-AP x NK-1-13	47th	899.1	104.0	30.3
48	39	CRG-AP x NK-12-13	48th	802.1	105.0	32.3
49	11	CRG-AP x NK-10-13	49th	771.9*	101.0	27.8
Grand Mean				**1,210.41**	**97.00**	**30.00**
LSD (0.05)				373.990	4.243	1.521

** Highest; * Least

Appendix 4: Combined mean performance for plant height, branch number per plant, pod number per plant, and pod yield per plant of the 49 groundnut genotypes

Entry No.	Genotypes	Plant Height	Branch No./ plant	Pod No./ per plant	Pod yield/ Plant
1	CRG-SH x AZ-3-13	43.2	9.4	26.8	23.5
2	CRG-AP x AZ-1-13	44.5	7.9	23.0	19.2
3	CRG-AP x AZ-8-13	39.9	8.5	23.3	18.6
4	CRG-SH x AZ-7-13	31.8	10.8	24.6	21.4
5	CRG-SH x AZ-4-13	39.7	10.3	27.5	21.3
6	CRG-AP x NK-2-13	47.8	9.1	26.0	23.4
7	CRG-SH x AZ-2-13	44.9	9.7	24.6	20.4
8	CRG-AP x AZ-13-13	45.1	8.0	23.1	20.2
9	CRG-AP x AZ-9-13	42.8	8.4	22.5	21.0
10	CRG-AP x NK-3-13	45.2	8.1	27.2	21.6
11	CRG-AP x NK-10-13	50.1**	9.6	22.3	17.8
12	CRG-NP x NK-7-13	43.8	8.6	22.9	22.2
13	Azivivi	37.0	13.1	21.7	18.9
14	Shitaochi-Local	39.4	10.4	24.2	19.2
15	CRG-AP x AZ-11-13	43.3	8.1	22.9	21.1
16	CRG-AP x AZ-6-13	42.4	8.9	26.6	22.8
17	CRG-AP x AZ-3-13	43.1	8.2	23.2	22.9
18	CRG-AP x NK-6-13	43.2	7.4*	27.6	26.8
19	CRG-AP x AZ-14-13	47.5	8.7	27.2	23.0
20	CRG-AP x AZ-2-13	42.5	9.2	23.2	23.8
21	CRG-AP x AZ-12-13	43.6	8.7	23.5	22.1
22	CRG-AP x NK-11-13	33.6	8.1	25.2	22.3
23	CRG-AP x NK-1-13	38.1	10.3	24.7	17.8
24	CRG-AP x NK-8-13	39.5	10.0	26.7	23.8
25	CRG-AP x AZ-7-13	44.8	7.5	21.4	19.3
26	CRG-NP x NK-3-13	36.8	14.2	22.8	20.8
27	CRG-SH x NK-1-13	35.0	15.7	22.9	24.9

Appendix 4 continued

28	CRG-AP x AZ-10-13	44.9	8.3	24.0	20.9
29	Nkosour	37.7	14.9	24.2	22.3
30	CRG-SH x AZ-1-13	41.2	11.9	18.8	18.7
31	CRG-AP x NK-9-13	35.3	12.3	28.6	18.2
32	CRG-AP x NK-5-13	44.8	9.7	25.2	24.2
33	CRG-AP x NK-4-13	44.0	9.1	20.2	19.7
34	CRG-NP x NK-2-13	32.3	11.4	27.5	23.6
35	CRG-AP x AZ-16-13	42.6	9.1	24.6	19.1
36	CRG-SH x AZ-5-13	43.5	9.3	23.3	23.4
37	CRG-AP x AZ-4-13	45.1	8.9	20.9	21.2
38	CRG-AP x AZ-15-13	46.7	8.6	26.1	22.2
39	CRG-AP x NK-12-13	31.3*	10.3	17.6*	14.6*
40	CRG-SH x AZ-6-13	36.6	11.2	30.7**	25.3
41	CRG-AP x AZ-5-13	43.2	9.4	24.2	19.6
42	CRG-SH x NK-2-13	38.8	11.0	25.0	23.8
43	Oboshie	35.9	9.1	19.0	27.1
44	Obolo	37.7	8.8	18.9	21.7
45	Yenyawoso	39.7	8.6	23.9	22.0
46	Adepa	33.7	15.0	18.3	17.9
47	Jenkaar	32.4	17.8**	23.8	22.1
48	Kumawu-Local	43.3	9.6	27.0	24.1
49	Otuhia	35.4	14.2	23.4	27.4**
Grand Mean		**40.70**	**10.10**	**24.00**	**21.61**
LSD (0.05)		3.600	1.697	5.684	5.496

** Highest; * Least

Appendix 5: Combined mean performance for 100-pod weight, number of seed per pod and shelling percentage of the 49 groundnut genotypes

Entry No.	Genotypes	100 Pod weight	Seed No./Pod	Shelling Percentage
1	CRG-SH x AZ-3-13	90.4	1.9	0.74
2	CRG-AP x AZ-1-13	89.2	1.9	0.72
3	CRG-AP x AZ-8-13	87.7	1.9	0.74
4	CRG-SH x AZ-7-13	88.7	1.8	0.65
5	CRG-SH x AZ-4-13	83.2	1.8	0.67
6	CRG-AP x NK-2-13	92.9	1.9	0.75**
7	CRG-SH x AZ-2-13	87.9	1.9	0.71
8	CRG-AP x AZ-13-13	87.2	1.8	0.72
9	CRG-AP x AZ-9-13	93.6	1.9	0.70
10	CRG-AP x NK-3-13	89.6	1.9	0.72
11	CRG-AP x NK-10-13	86.3	1.8	0.71
12	CRG-NP x NK-7-13	100.1	1.7	0.66
13	Azivivi	96.3	1.8	0.66
14	Shitaochi-Local	87.7	2.1**	0.70
15	CRG-AP x AZ-11-13	89.5	1.9	0.74
16	CRG-AP x AZ-6-13	89.6	1.9	0.74
17	CRG-AP x AZ-3-13	107.1	1.9	0.67
18	CRG-AP x NK-6-13	106.0	1.8	0.65
19	CRG-AP x AZ-14-13	93.0	2.0	0.71
20	CRG-AP x AZ-2-13	109.8	1.9	0.72
21	CRG-AP x AZ-12-13	95.9	1.9	0.74
22	CRG-AP x NK-11-13	87.7	1.7	0.69
23	CRG-AP x NK-1-13	80.1	1.7	0.68
24	CRG-AP x NK-8-13	88.4	1.8	0.69
25	CRG-AP x AZ-7-13	87.9	1.9	0.71
26	CRG-NP x NK-3-13	99.7	1.8	0.65
27	CRG-SH x NK-1-13	114.0	1.8	0.68

** Highest; * Least

Appendix 5 continued

28	CRG-AP x AZ-10-13	90.1	1.9	0.69
29	Nkosour	97.1	1.8	0.64
30	CRG-SH x AZ-1-13	104.5	1.7	0.65
31	CRG-AP x NK-9-13	67.3*	1.9	0.71
32	CRG-AP x NK-5-13	97.3	2.1	0.71
33	CRG-AP x NK-4-13	100.9	1.9	0.67
34	CRG-NP x NK-2-13	87.4	1.7	0.67
35	CRG-AP x AZ-16-13	89.0	1.9	0.73
36	CRG-SH x AZ-5-13	107.5	2.0	0.69
37	CRG-AP x AZ-4-13	103.5	2.1**	0.72
38	CRG-AP x AZ-15-13	89.1	1.9	0.72
39	CRG-AP x NK-12-13	73.5	1.5*	0.52*
40	CRG-SH x AZ-6-13	91.5	1.9	0.69
41	CRG-AP x AZ-5-13	91.3	1.9	0.72
42	CRG-SH x NK-2-13	105.9	1.8	0.70
43	Oboshie	151.7	1.7	0.62
44	Obolo	123.7	1.7	0.59
45	Yenyawoso	106.0	1.9	0.66
46	Adepa	99.0	1.6	0.65
47	Jenkaar	100.0	1.8	0.65
48	Kumawu-Local	92.6	1.9	0.67
49	Otuhia	117.4	1.8	0.66
Grand Mean		**95.83**	**1.85**	**0.69**
LSD (0.05)		9.603	0.143	0.038

** Highest; * Least