EVALUATION OF GENETIC VARIABILITY IN AGRO-MORPHOLOGICAL AND FRUIT QUALITY TRAITS OF SOME HOT PEPPER (*Capsicum sp*.) GENOTYPES

BY

ACKEY REXFORD

(10442188)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY IN CROP SCIENCE DEGREE

JULY, 2015.

DECLARATION

I, Ackey Rexford, thereby declare that except for the references to other people's work, which have been duly cited, this thesis is the result of my original findings and this thesis has neither in whole, nor part, been presented for a degree in Ghana or elsewhere.

ACKEY REXFORD SIGNATURE……....

(STUDENT) DATE……

PROF.E.T.BLAY SIGNATURE……....

(SUPERVISOR) DATE……

PROF.G.O.NKANSAH SIGNATURE……....

(SUPERVISOR) DATE……

PROF.I.K.ASANTE SIGNATURE……....

(SUPERVISOR) DATE……

ABSTRACT

Determination of genetic variability among genotypes is highly desirable for selection towards crop improvement and production. The main objective of this study was to evaluate variability in agro-morphological and fruit quality traits in seventeen (17) hot pepper genotypes under greenhouse and field conditions. The experiment was laid out in Randomized Complete Block Design with three replications under greenhouse and field environments. The estimation of genetic variance under individual environments, showed high broad sense heritability in most traits studied. Under both greenhouse and field conditions, broad sense heritability for agro-morphological traits ranged between 0 % (stem girth) and 96.94 (number of seeds per fruit) while antioxidant properties ranged between 5.91 % (Lycopene content) and 100 % (IC_{50} value). Except for antioxidant properties under field conditions, genetic advance by percentage mean was high under both environments and it ranged between 0 % (stem girth) and 130.82 % (yield in tons per hectare) for agro-morphological traits while antioxidant properties ranged between 5.76 % (Vanillic acid content) and 73.82 % (β carotene). In general, phenotypic coefficient of variation (13.89 % - 97.08 %) was higher than the genotypic coefficient of variation (0 % - 82.87 %) in all the traits studied under both environments. The combined analysis showed highly significant difference ($P<0.001$) among most traits studied for genotype, environment and genotype x environment interaction. Days to 50 % fruiting and flowering was significant and had positive associated with most of the traits studied. Among the traits, performance varied among genotypes and across environments showing adequate genetic variability which could be based on for selection.

DEDICATION

I dedicate this work to my dear wife Mrs. Ackey Okyere Okobea Mavis, for her support in material and spiritually throughout my programme. It is also to my dear and lovely daughters, Anna Kyei Twumasi-Ankrah and Nhyirabah Okyerewa Twumasi-Ankrah.

ACKNOWLEDGEMENT

I sincerely thank the almighty God Jehovah, for provision, guidance, and protection upon my life throughout my two year degree programme.

I would also like to appreciate the immense contribution of my supervisors Prof. E.T. Blay, Prof. G.O. Nkansah, and Prof. I. K. Asante throughout my project work.

I am also indebted to Messrs. D.J. Boateng, Awutey Edem Felix, Naab Armstrong Roland and Miss Addae Elizabeth of Achiase Senior High School, Akim Achiase for their support in diverse ways during my studies.

Finally, I would like to appreciate my parents and siblings especially Ackey Eric for their support throughout this two year period.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

µl	Microliter
^{0}C	Degrees Celcius
BC	β Carotene
CACS	College of Agriculture and Consumer Sciences
CCF	Chlorophyll Content at Flowering Stage
CCH	Chlorophyll Content at Harvest
CW	Canopy Width
Del H	Genotype Delhi Hot
Df	Degree of Freedom
DFR	Days to First Fruit Ripe
DPPH	2, 2-Diphenyl-1-picryhydrazyl
DtF	Days to 50% Flowering
DTF	Days to 50% Fruiting
E x G	Environment x Genotype Interaction
EGA	Expected Genetic Advance
Env.	Environment
F	Flowering Stage
FC	Total Flavonoids
FL	Fruit Length
FOHCREC	Forest and Horticultural Crops Research Centre
FW	Fruit Width
FWT	Fruit Wall Thickness

FWT	Fruit Wall Thickness
g	Number of Genotypes
GA	Gallic Acid
GA %	Genetic Advance by Percentage
Gal	Genotype Galaxy
GCV	Genotypic Coefficient of Variation
GR	Genotype GR 202
Grand M	Grand Mean
Green H	Greenhouse
H	Harvest
h^2	Heritability
ha	Hectare
IC_{50}	Inhibition coefficient at 50%
ICP	Genotype ICPN16#7
k	Selection Intensity
L 18	Genotype Legon 18
l	Location/ Environment
LC	Lycopene
LHC	Genotype Local Hot Chilli
LSD	Least Significant Difference
MF	Genotype Mayford
MS_b	Replication Mean Square
Ms_e	Error Mean Square

Ms_g	Genotypic Mean Square
MSl	Location Mean Square
MSr (l)	Replication x Location Mean Square
N.P.K	Nitrogen Phosphorus Potassium
nm	Nanometer
NOF	Number of Fruits per Plant
NOL	Number of Leaves
NOS	Number of Seeds per Fruit
PCV	Phenotypic Coefficient of Variation
PGRRI	Plant Genetics
PH	Plant Height
pH	Power of Hydrogen
PM	Genotype Pari Mild
r	Replication
RA	Rosmarinic Acid
RE	Rutin Equivalent
Rep.	Replication
S. Variation	Source of Variation
Sal	Genotype Salmon Pepper
SG	Stem Girth
ton	tonne
VA	Vanillic Acid
Vul	Genotype Vulcano

x	Mean
XLSTAT	Excel Statistical Software
YTH	Yield (ton/ha)
σ^2_g	Genetic Variance
σ^2_e	Environmental Variance

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Background

Pepper belongs to the genus *Capsicum* and is a member of the Solanaceae family that includes tomato, potato, tobacco and egg plant. The genus originated from Central and South America (Dagnoko *et al.,* 2013). Pepper is the most important spice and vegetable crop in the world (Berhanu *et al.,* 2011). It is considered to be the first spice to be used by man. There is archaeological evidence of pepper and other fossil foods from as early as 6000 years ago (Hill *et al.*, 2013). The genus *Capsicum* has twenty-five wild and five domesticated species (Bosland and Votava, 2000; (Nkansah *et al.*, 2011). The domesticated species are *Capsicum annuum, Capsicum frutescens, Capsicum chinense, Capsicum pubescens and Capsicum baccatum*. Among these, *Capsicum annuum* is the best known domesticated species in the world (Hot, 2010). The non-pungent form (bell pepper) is used by many people as green vegetable and chili peppers used as spice or condiment (Singh *et al.*, 2006).

Hot pepper is one of the most famous and used spices in the world. Thus, it is now an integral part of most cultures of the world. Christopher Columbus is credited for the introduction of hot pepper to Europe in 1492 from America (Hot, 2010). *Capsicum chinense* is the hottest among the *Capsicum* species and Habanero and Scotch Bonnet are the hottest varieties of *Capsicum chinense (*Singh *et al*., 2006). Ted *et al*. (2012) reported that pungency is the most notable characteristic of hot peppers. The reason most people eat chili pepper is the heat or pungency associated with the fruit (Paul and Stephanie, 2010). Thus, it is also one of the general parameters considered for export (CEDA 2009). The pungency of hot pepper is due to one of its capsaicinoids (alkaloids) components of which the main one is capsaicin.

Capsicum (sweet and hot) has many benefits. Its potential uses and benefits cover many areas such as food and nutrition, medicine, cosmetics, plant based insecticides (PBI), crime

control/aerosols, and income generation (Dagnoko *et al*., 2013). Nutritionally, hot pepper like any other *Capsicum* species is rich in vitamin A and C, calcium, phosphorus, and potassium. It has been reported that peppers are highly appreciated for their spicy flavor and nutritional value (Miguel *et al.*, 2010). Medically, extract from hot pepper is known to be used for pain relief products (Berke and Shieh, 2001). Hot pepper can also be used for cosmetic production (Rehima, 2006). Ceballos-Muller and Toon, 2010.

Pepper is a common agricultural product produced and consumed in Ghana (Cellabos –Muller and Toon, 2010). It is one of the major vegetable crops exported in Ghana. It is a good income source for small producers and is significantly one of the foreign exchange earning vegetable crops (Bonsu *et al*., 2003). MiDA (2010) also reported that Chili peppers production in Ghana has been mainly for local consumption. However, export to the European market has been increasing. Ghana is the fifth largest exporter of chili peppers to the European Union and the demand of pepper has been increasing yearly by 17 percent on average since 2000 (MiDA, 2010). Despite this encouraging improvement that hot pepper has added to the export value of vegetables , statistics indicate that vegetable exports from Ghana decreased from 4, 156.2 tons in 2006 to 2, 165.1 tons in 2009 with a corresponding decrease in cash value from $2, 305, 825 (GH¢2, 123, 409) to 1, 308, 218 (GH¢1, 861, 974). There was therefore a 46% decrease in export quantities but with 36% increase in cash value in 2010. The decrease in vegetable production and export (including hot pepper) can mainly be attributed to lack of good planting materials or varieties that meet export standards (Nkansah *et al.*, 2011).

Because the vegetable seed industry in Ghana is not potent, local seed companies import exotic seeds to satisfy local producers. Thus, farmers grow both the local and exotic varieties. There is also limited and current agronomic data on the performance of both local and exotic genotypes. Producers therefore are likely to continue planting varieties with low economic potential (Kwatei *et al*., 2014). Again, it has been reported that pepper producers in Ghana are

realizing about half the percentage of the attainable yields which indicates low production (MiDA, 2010). This may be assigned to low soil fertility, pests and diseases pressure, unavailability and high cost of irrigation systems, inadequate knowledge of improved technologies and the use of unimproved varieties (MiDA, 2010). It is essential then to assess the potential of the genetic stock of hot pepper varieties in order to have a clear picture of their genetic constitution and heritable proportion of important traits to facilitate selection for production and improvement programs.

Nyadanu *et al.* (2014), have reported that it is no longer an option but a necessity to breed improved varieties which satisfies the preferences of farmers and consumers in Africa.

1.2 Objectives

The main objective of the study was to evaluate variability in agro-morphological and fruit quality traits in hot pepper genotypes to aid selection of genotypes for commercial production as well as pepper improvement programs.

1.3 Specific Objectives

The specific objectives of the study were to:

- evaluate some agro-morphological and fruit quality characters of hot pepper genotypes
- determine genetic variation among hot pepper genotypes using phenotypic characters
- estimate heritability and interrelationship of the traits studied
- identify and select superior genotypes based on agro-morphological characters and some fruit quality traits.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Classification and Taxonomy of *Capsicum* Species

Pepper (sweet and hot) belongs to the genus *Capsicum.* The genus is a member of the Solanaceae family which include important crops such as eggplant, tomato, potato, tobacco, and petunia (Bosland, 1996). It is in the sub-family *Solanoideae* and tribe *Capsiceae* (Knapp *et al*., 2004). *Capsicum* species are diploids and most have 24 chromosomes ($n = x = 12$) with several wild species having 26 chromosomes ($n = x = 13$) (Tong and Bosland, 2003). Peppers are perennial woody plants but grown as herbaceous annuals in temperate areas (Jeffrey, 2005). *Capsicum* originated from Central and South America (Grubben and Mohammed, 2004). Christopher Columbus is credited for the discovery of *Capsicum* in 1492. It is believed that pepper has the earliest culinary history from far back 7000 BC (Debra, 2003). The genus *Capsicum* has five domesticated species namely: *Capsicum annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens (*Berke and Shieh, 2001). It is estimated to have twenty five species. This is expected to expand with new species to be discovered (Eshbaugh, 1993). *Capsicum annuum* is the most cultivated among the five species (Csillery, 2006). The five domesticated species are further grouped into two taxonomic complexes; *Capsicum annuum*, *C. frutescens* and *C. chinense in* one group (Pickersgill, 1988) while *C. baccatum* and *C. pubescens* are also in another complex (Walsh and Hoot, 2001).

2.2 Morphology of *Capsicum* Species

Domesticated *Capsicum* species are differentiated by using morphological traits based on colour and flower morphology and seeds (Andrews, 1995). The flower of this genus is bisexual, hypogynous and mostly pentamerous (Bosland and Votava, 2000). In *C. annuum,* the flower is solitary. However, in other species they are borne in cymule especially in *C. chinense and C. frutescens.* The flowers are usually white but occasionally tinged with purple, and are borne

in the axils of the leaves or branches (Jeffrey, 2005). They have complete flowers with calyx, corolla, and male and female sex organs. The *Capsicum* calyx is broadly campanulate, ribbed, and about 2 mm long (Dharamadhaj and Prakash, 1978). The genus usually has five stamens with bluish anthers which are joined to the base of the corolla. The stamens dehisce longitudinally, exposing the pollen. *Capsicum* species have single style which are often longer than the stamens, especially in hot peppers. Stigma is club-shaped and in the domesticated the number of locules may vary between two and four or more. Variation is not in the number of locules in the same plant (Jeffrey, 2005).

Capsicum fruit is a berry (Knapp, 2002). Extensively, variations exist in fruit shape, size, wall thickness and fleshiness, colour and pungency. These are influenced by genetic and environmental factors (Andrews, 1995). Fruits at the tender stages are usually borne in an erect position. However, in some varieties it turns downward into a pendant position as it grows (Jeffrey, 2005). Pod length varies from less than 1 to 32.5 cm. The pedicel length also varies in different pod types. Fruit colours range from green, yellow, orange red /purple, brown, black, and white. (Chaim *et al*., 2003). Cultivated fruit reaches the mature green stage in 35-50 days after the flower is pollinated (Bosland and Votava, 2000).

The seeds of *Capsicum* are attached to the placenta walls. Seeds lack pubescence except for *Capsicum pubescens*. Seed weight varies according to species, variety, and growing conditions (Jeffrey, 2005).

2.3 Environmental and Growth Conditions of *Capsicum* Species

Capsicum species do not do well on dry or compacted soils. Sandy loam with pH range of 5.5-6.8 is suitable for production. Well drained, efficient and constant supply of moisture are beneficial for production (Jeffrey, 2005). It is prone to frost damage (Watkins and Cantliffe, 1983a). Optimum day and night temperatures for seedlings and young plants range between 24 ^{o}C - 29 ^{o}C and 10 ^{o}C to 16 ^{o}C. The best temperature for fruit set ranges between 18 ^{o}C and 27

°C (Jeffrey, 2005). Efficient seed germination requires a constant temperature ranging between 15 °C and 30 °C (Randle and Homna, 1980; *cf.* Dell'Aquila, 2004). Germination does not occur when seeds are exposed to temperatures below 8 °C or above 40 °C (Choi, 1985). In domesticated species, seed germination does not depend on any strict light requirements (Hernandez-Verdugo *et al*., 2001b). Peppers grown under greenhouse conditions are taller, and develop fragile tissue than those planted on the field (Gomez-Guillamon and Cuartero, 1987). *Capsicum* species are usually indeterminate. They have continuous sympodial branching with the individual branch systems functioning as relatively autonomous integrated physiological units (Thomas and Watson, 1988; *cf.* de Swart *et al*., 2004). Anthesis in pepper starts from 30-42 days after planting (Gibbon and Pain, 1985; Khah and Passam, 1992). It is controlled by day length (Aleemullah *et al*., 2000). High temperature during fruit set has negative influence on productivity while low temperature deforms fruit shape (Rylski and Spigelman, 1982; Rylski, 1972).

2.4 Importance of *Capsicum* Species

Pepper serves as a condiment in diverse dishes. The fruits are consumed fresh, dried or in processed form (Geleta, 1998; Seleshi, 2011). It has several nutritional benefits. The genus is rich in Vitamins A and C (Bosland and Votava, 2000). Lee and Kader (2000) reported that some pepper varieties contain seven times more vitamin C than orange. The vitamins A, C and beta-carotenoids in pepper are known to be powerful antioxidants (Simonne *et al*., 1997). Pepper may also contain magnesium, iron, thiamin, riboflavin, and niacin (Debra, 2003). Red form of *Capsicum* fruits contains lycopene and this is believed to have anti-cancer properties (Simmone *et al*., 1997).

Capsicum species has many medicinal benefits. Their medicinal use dates back to the days of the Mayas. They used them to treat asthma, coughs, and sore throats (Bosland, 1996). Pepper can also be used for the treatment of fevers and colds (Norman, 1992). Pharmaceutically, the

active compound capsaicin is used as a counter-irritant balm for external application (Carmichael, 1991). It is the active ingredient in Heet and Sloan's Liniment, two rubdown liniments used for sore muscles (Bosland, 1996). *Capsicum* influences circulation, relieves gas and colic, aids digestion, and prevent infection in the body (Debra, 2003). Another beneficial use of pepper is in the area of crop protection where extracts from pepper is used as bio-insecticide. Bouchelta *et al*. (2003, 2005) reported that pepper extracts used on eggs and adults of the *tabaci* whitefly proved to be potent. Chili extracts applied on thrips, pod borers, and pod suckers on cowpea reduced their population (Oparaeke *et al.*, 2005). Secondary metabolites such as alkaloids, saponins and flavonoid in *Capsicum* species are a source of toxicity which affect insects (Bouchelta *et al.*, 2005). Oleoresin in pepper is used as spray to act as a non-lethal repellent to both animal and human targets (De, 2003) and serves as a valuable riot control agent and self-defense tool (Sanatombi and Sharma, 2006).

2.5 Breeding in *Capsicum* Species

Breeding in plants is required to enhance the value of food crops, by improving their yield and the nutritional quality of their products. Breeders have developed cultivars with modified physiology to cope with variations in environments which is alien to them. New cultivars also need to be developed for resistance against various biotic factors such as diseases, insect pests and abiotic factors such as salt, drought, heat, and cold (Acquaah, 2007).

Traits such as high yield, pungency, fruit colour, fruit size and shape as well as disease resistance are considered for selection in breeding pepper. These are considered based on the objectives for the breeding (Liu *et al*., 2009). However, breeding for resistance to several economically important diseases is one of the major focus in pepper improvement program (Gniffke *et al*, 2013).

The flowers of *Capsicum* species have large ovary surmounted by a style that is generally longer than the surrounding stamens. However, the stigma is usually receptive prior to the

release of pollen (Free, 1993). Pepper is prevalently an autogamous species but frequently experiences cross-pollination (Csillery *et al*., 1986; Tay, 1989). Again, it has been reported that hot pepper species have longer styles and therefore facilitates cross pollination (Jeffrey, 2005). Walter (1986) reported that bees account for natural crossing in pepper and this results in variability in cultivars.

Although *Capsicum* species do not hybridise with species in other genera of solanaceae (Berke, 2000), interspecific crossing between many *Capsicum* species has been evaluated for agronomic and taxonomic purposes (*cf.* Walsh and Hoot, 2001; Pickersgill, 1991, 1997; Onus and Pickersgill, 2004). Hybridizations within the taxa of the *Capsicum annuum* complex produce fertile hybrids to various extents (Jarret and Dang, 2004; Nwankiti, 1976; Kumar *et al*., 1987; Panda *et al*., 2004; Baral and Bosland, 2004). Generating interspecific hybrids within species of different gene complexes in *Capsicum*, mostly have not been obtained. This is due to incompatibility between species, abortion of the embryo and male sterility (Onus and Pickersgill, 2004, Pickersgill, 1997). Singh (1993) reported that the more distant two species are genetically, the more sterile their hybrid. Thus, it is necessary to assess accessions for pollen viability in interspecific hybridization during breeding (Carlos *et al*., 2011).

2.6. Germplasm Characterization and Evaluation in *Capsicum* Species

Germplasm characterization involves programmed and systematic collection of data based on the assessment of features that describe and differentiate accessions (Almeida *et al.*, 2005) and evaluation is the description of the material in a collection (Thomas and Mathur, 1991).

In characterization, clearly different identifiable traits which are heritable are recorded. It is carried out in precision fields through spaced planting under adequate agronomic conditions and plant protection (Upadhyaya *et al*., 2008). Characterization and evaluation of conserved genotypes are of basic importance for enhancing the breeder's ability to identify elite genotypes for use in breeding programs (Laurentin, 2009; Elizanilda *et al*., 2011).

2.7 Significance of Genetic Improvement in *Capsicum* Species

The use of plant genetic resources in crop improvement results in evolution of improved cultivars for cultivation and consumption. It also serves as one of the most sustainable methods to conserve valuable genetic resources for the future. More so, it ensures an increase in agricultural production as well as food security (Haussmann *et al*., 2004). More efficient use of plant genetic diversity is a prerequisite to meeting the challenges of development, food security and poverty alleviation (FAO, 1996b). Improved crop varieties with superior agronomic and quality traits results from plant breeding programs. Plant breeding alters the heritable patterns of plants to increase their value (Columbia Encyclopedia, 2008). Crop breeding programs can employ both traditional and modern biotechnology methods to identify varieties with traits relevant to climate change. This can be done to increase varietal tolerance to factors such as high temperatures, extreme heat, droughts, flooding, and high salinity (ADB, 2014). The huge genetic diversity available for chili breeders has facilitated the development of new varieties and hybrids (Maheshwari and Chandrashekhar, 2011).

2.8 Agro-morphological Characterization of *Capsicum* Species

Morphological, agronomic, genetic and physiological features cannot be ignored when making selection among varieties (Ndour, 1998). Traditionally, *Capsicum* species are recognized by morphological descriptors or related traits (Sudre *et al*., 2010). Although determination of genetic divergence in accessions is accurate using molecular markers, concept of the phenotype given by morphological and agronomic descriptors is still essential (Goncalves *et al.*, 2008). According to Agyare (2013), using morphological and molecular markers for genetic characterization is necessary for gathering pertinent information on genetic divergence within species. Such record serves as the fundamentals for provision of proper conservation strategies as well as instituting effective breeding methods (Agyare, 2013). An idea about the phenotype obtained through morphological descriptors is key to accurate species identification (Dias *et*

al., 2013; Aziagba *et al*., 2015). According to Bajracharya *et al.* (2006), characterization is used to assess phenotypic diversity by using agro-morphological traits.

Effective breeding in pepper depends on genetic variation of accessions in useful agronomic traits (Mehmet and Dursun, 2011). According to Rao (2004), in spite of the low productive characters of *Capsicum* landraces, subsistent farmers use them because of their desirable agronomic characteristics. Thus characterizing pepper germplasm for such traits is very essential.

2.9 Phytochemical Composition of *Capsicum* Fruits

Plants contain vast range of chemicals some of which are beneficial to the plant itself, animals and human. According to Heneman and Zidenberg-Cherr (2008), phytochemicals are compounds from plants that have the potency to prevent diseases in human. Phytochemicals are found in medicinal plants and organs such a leaves, roots, seeds and fruits of crop plants. It is categorized into primary and secondary compounds. Primary consist of compounds such as chlorophyll and protein while secondary include terpenoid, alkaloid and phenolic compounds (Nostro *et al*., 2000). There has been an increase interest in the analysis of crop plants for phytochemicals by commercial and pharmaceutical companies (Wadood *et al*., 2013) which *Capsicum* species are not exception. Aziagba *et al*. (2013) reported that *Capsicum* species are not only grown for their spicy nature, vegetable and nutritional value but also for medicine. According to Lee *et al*. (2005), the species have diverse biochemical and pharmacological properties such as antioxidants, anti-inflammatory, anti-allergenic and anti-carcinogenic activities.

2.9.1 Antioxidant Properties of *Capsicum* Species

Antioxidants are chemical components which have the ability to react with free radicals to stop or prevent their interaction with biological tissues. This is achieved through scavenging activity by the antioxidants, chelating of metal ions and to reduce the quantum of localized oxygen

concentration. (Asimi *et al*., 2013). Antioxidant compounds include carotenoids, vitamins, and polyphenols. These can further be categorized into i) carotenoids consisting of carotenes and xanthophylls ii) vitamins as C and E iii) Polyphenols classified into flavonoids, phenolic acids, lignans and stilbenes (Oroian and Escrihe, 2015).

2.9.1.1 Carotenoids (β carotene and lycopene)

Carotenoids are among the diverse sources of plant pigments (Van den Berg *et al*., 2000). There are about 60 carotenoids obtained from fruits and vegetables from which β carotene and lycopene are among the most important (Oroian and Escrihe, 2015). Pepper is a very good source of carotenoids (Deepa *et al*., 2007).

Among carotenoids, β carotene is the highest studied compound (Krinsky and Johnson, 2005)**.** β carotene is a pro-vitamin. However, the body has the ability to change it to vitamin A. According to Deepa *et al.* (2007), environmental factors and the extent of ripening influence the content of β carotene in pepper. Vera-Guzman *et al*. (2011) reported on a range of 29.3 – 132.9 mg/100g of β carotene in ripe fruit of pepper while Chavez-Mendoza *et al.* (2013) reported on a range of 0.0039 - 0.0074 mg/g in grafted pepper. Medically, β carotene has been reported to give protection against cancer especially, breast, prostate and lung cancer (Chavez-Mendoza *et al.* 2013). This is due to its antioxidant function as a scavenger of free radicals. (Burton and Ingold, 1984). Acting as antioxidant, its reactivity with peroxyl is faster than that of unsaturated acyl chains (Woodall *et al*., 1997). It has been reported that β carotene can give immunity to certain cells in the body. Study of β carotene has shown a mechanism of protection of phagocytes from auto-oxidative attack and its ability to influence other activities such as T and B lymphocyte production and tumoricidal properties (Bendich, 1989).

Lycopene is a highly unsaturated compound. It has 13 bonds of which 11 are conjugated. It is a highly powerful antioxidant and its quality has been found to be as twice as that of β carotene. Lycopene by its singlet oxygen quenching function is about ten folds higher than α tocopherol

(Rao *et al*., 2003). Lycopene can be obtained from plant sources such as carrot, grapefruit, water melon, and papaya and pepper (Zuknik *et al.*, 2012). Chavez-Mendoza *et al*. (2013) reported a range of 0.0025 - 0.0048 mg/g for lycopene content in pepper. According to Basu and Imrhan (2006), lycopene has anti-carcinogenic qualities which are beneficial to human health. Lycopene has been found to prevent oxidative damage to DNA (Matos *et al*., 2001).

2.9.1.2 Polyphenols (Gallic, Vanillic and Rosmarinic Acids and Flavonoids)

Polyphenols are diverse range of compounds which are biological in nature. Polyphenols consist of phenolic acids, flavonoids, phenolic alcohol, lignans, and stilbenes. These compounds give protection to plants by toughening, maintaining cell walls (Furiga *et al.,* 2009) and preventing microbial infections (Geissman and Hinreiner, 1952). Polyphenols mostly occur as natural antioxidants which are safer than the synthetic (Okubo *et al*., 2003). Research has shown that polyphenols influence the healing process of wounds and possess immunity modulation qualities against carcinogenic pathways (Paszkiewicz *et al,* 2012) .There has been an increase in the study of food phenolic compounds which is attributed to the antioxidant properties and its activity (Kuljarachanan *et al*., 2009; Ahmed *et al*., 2015). Perucka and Meterska (2001) reported that *Capsicum* species possess high quality phenolic compounds. Capsaicin, a polyphenol from pepper has been reported by Surh and Seoul (2002) to have anti-mutagenic and anti-carcinogenic qualities. The concentration of polyphenol is affected by the environment and extent of maturation. These affect pungency, flavor and colour of fruit (Nadeem *et al*. 2011). Campos *et al.* (2013) reported on total phenols in pepper genotypes within the range of 20.54 and 20.75 mg/100g.

Phenolic acids belong to the main class of polyphenols (Cai *et al.,* 2004) and gallic, vanillic and rosmarinic acids fall under this.

Flavonoids are compounds with different phenolic structure. There are more than 4000 different types of flavonoids discovered. Anthocyanins, flavonols, chalcones, and flavones are

examples of flavonoids. Structurally, flavonoids have two benzene rings with fifteen carbons (Middleton, 1998). Flavonoids are the most abundant polyphenols and are found in photosynthetic portions of plants. Some sources of flavonoids are pepper, tomato, citrus, onion and soya bean. There are several benefits derived from flavonoids. In flowering plants, it is a major determinant of colour composition (Koes, 2005). The increase in the study of health benefits from medicinal plants currently, could be attributed to their flavonoids qualities (Pourmorad, 2006). Antioxidant property of flavonoids is the best biochemical quality it posseses. The antioxidant function of flavonoids is carried out through suppression of reactive oxidative species, scavenging reactive oxidative species and protection of antioxidant defense (Halliwell and Gutteridge, 1998; Mishra *et al*., 2013).

Flavonoids in plant food have been reported to reduce the risk of cancer diseases (Hertog *et al*., 1994;Wolfe and Liu, 2008). Flavonoids are essential for the prevention of chronic diseases as osteoporosis and diabetes (Sherakat, 2009). Flavonoids also add up to the colour of food (Nisha and Arulmozhi, 2013). Perucka and Materska (2001) reported that ripe pepper have high flavonoid content.

2.9.2 Antioxidant Activity of *Capsicum* Species

Antioxidants are compounds which have the ability to impede the activities of reactive oxidative species by stopping or reducing their damage to biomolecules. Compounds which have antioxidant properties include vitamins, carotenoids, and polyphenols (Oroian and Escriche, 2015). Antioxidant activity is the process where antioxidant initiates a protective mechanism to neutralize reactive oxygen species (Goldfarb, 1993). To determine the antioxidant activity of a substance, one of the commonly used method is the reaction of 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) with the substance (extract) in methanol solution. Reduction of DPPH is monitored through a decrease in its absorbance at a wavelength of 515nm during the reaction. The antiradical activity (EC_{50}- efficient concentration) is recorded.

EC_{50} is the quantity of the antioxidant needed to reduce the initial DPPH concentration by 50%. Lower EC_{50} value indicates higher antiradical activity by the antioxidant compound (Brand-Williams, 1995). For the relationship between antioxidant and antioxidant activity, Saidu and Garba (2011) reported that there was a positive relationship between total phenolic content and antioxidant activity in pepper extract. They further stated that the extent of antioxidant activity was highly attributable to phenolic compounds.

2.10 Variability in *Capsicum* Species

Variability expresses the divergence that exists among individuals in a population. It is expressed by the outward characteristics of an individual which is referred to as the phenotypic characteristics. In plants, it includes the visual traits such as flower, plant stature, resistance to pest etc. Phenotype is influenced by both the environment and the genetic composition of the individual plant (Arnel, 2011). Thus, the interaction between the two influences the phenotypic expression of a trait. Genotype x environment interaction can therefore be defined as a change in the performance of a trait when two or more genotypes are evaluated in two or more environments (Bowman, 1972).

The extent of variation among individuals is measured as variance. Thus, total variation that shows phenotypically in an individual is referred to as the phenotypic variance (total variance). Basically, its components are the genotypic (V_G) and environmental (V_E) variances. However, these component does not really justify the source of resemblance among the individuals and the magnitude of their genetic properties. To achieve these, the genotypic variance (V_G) is separated into additive (V_A), dominance (V_D) and interaction (V_I) variances (Falconer, 1960). The degree to which the phenotype of a trait is influenced by its genetic composition is determined by heritability. According to Nyquist (1991) heritability (h^2) is the proportion of the phenotypic variance which comes from the gene influence. It is estimated as the ratio of the genotypic variance (σ^2_g) to the phenotypic (σ^2_p) variance (Falconer, 1960). Heritability

shows the extent to which a trait is transmittable from a parent to the off-spring. The degree of heritability estimates determines how improvement is feasible by selection (Nechif, 2011). However, heritability alone does not aid efficient selection. High heritability with high genetic process in a trait indicates potentiality for selection. Variability, heredity together with genetic advance in pepper stand for high values that could be enhanced in breeding programs (Sreelathakumary, 2004). It has also been reported by Omoigui *et al* (2006) that different components of genetic variance and heritability are necessary for estimating selection efficiency.

Other parameters as genotypic and phenotypic coefficients of variations also help to determine the degree to which the phenotypic expression of a trait is influenced by the environment and/ or the genetic factor. According to Rajib and Tah (2011) the degree of variation in different traits is estimated by genotypic (GCV) and phenotypic (PCV) coefficients of variation. They further stated that any genetical enhancement of a crop is dependent on the extent of the measure of genetic parameters as genotypic (GCV) and phenotypic (PCV) coefficients of variation, genetic advance (GA) and heritability (h^2).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The research work took place in two locations. Planting, growth and agro-morphological studies were conducted under greenhouse and field conditions at the Forest and Horticultural Crops Research Centre (FOHCREC) of the University of Ghana at Kade in the Kwaebirim District, Eastern Region of Ghana. It is located 123 km north-west of Accra and 114 m above sea level on latitude 60.0854'N and longitude 0.5400'W in the semi-deciduous forest agro-ecological zone (CACS, 2010). The laboratory analyses were conducted at the Department of Botany, College of Basic and Applied Sciences of University of Ghana Campus, Accra.

3.2 Soil and Climate

Haplic Acrisol type of soil is the characteristic of the entire research site (Nkansah *et al*., 2011). Climate of the area is classified as humid tropical (Ofosu-Budu, 2003). Temperature of the area ranges between 25 ^{o}C and 38 ^{o}C with an annual rainfall ranging between 1300 mm and 1700 mm. The rainfall pattern is bi-annual (Nkansah *et al*., 2011).

3.2.1 Soil for Greenhouse and Field Experiments

Table 1 gives the composition of organic matter, pH, nitrogen, phosphorus and potassium contents in the soil samples under both field and the greenhouse conditions.

Table 1: Nutrients, organic matter, and pH contents of the soils used under field and greenhouse conditions

Soil resource	Field	Greenhouse
Organic Matter	2.26 %	3.37 %
Potassium	0.6 cm/kg	0.75 cm/kg
Phosphorus	7.74 mg/kg	8.02 mg/kg
Nitrogen	0.23 %	0.32 %
pH	6.3	6.78

Source: Soil Science Laboratory, University of Ghana, Legon.

3.2.2 Climatic Conditions during the Period of the Experiment

Climatic conditions during the period of the experiment (under both greenhouse and field conditions) are given in the Tables 2 and 3.

Table *2:* Climatic conditions from November 2014 –April 2015 under greenhouse conditions

	Temperature		Relative humidity	
Month	Maximum	Minimum	Maximum	Minimum
November, 2014	40.70	16.70	79.89	31.23
December, 2014	39.26	16.70	81.20	34.23
January, 2015	40.65	16.68	88.40	33.25
February, 2015	40.34	16.71	82.30	34.24
March, 2015	39.34	16.13	80.13	33.23
April, 2015	38.34	16.15	81.12	34.24

Source: FOHCREC, Kade.

Table 3: Climatic conditions from November 2014 –April 2015 under field conditions

	Temperature (^{0}C)		Relative humidity (%)		Rainfall
Month	Maximum	Minimum	Maximum	Minimum	(mm)
November, 2014	34.40	23.51	94.98	39.52	0.47
December, 2024	34.57	22.79	99.11	45.15	1.90
January, 2015	34.57	22.54	98.64	46.19	2.11
February, 2015	34.80	22.60	99.43	47.75	0.70
March, 2015	34.45	22.11	99.67	46.20	2.10
April, 2015	33.98	22.01	99.23	44.65	2.04

Source: FOHCREC, Kade

3.3 Pepper Genotypes used for the Experiment

Seventeen (17) genotypes obtained from Plant Genetic Resources Research Institute (PGRRI), Bunso and Forest and Horticultural Crops Research Centre (FOHCREC), Kade were used for the experiment. The genotypes and their sources are indicated in Table 4.

Table 4: Sources of genotypes used for the study

GENOTYPE	SOURCE
Galaxy	FOHCREC –Kade
GR 202	FOHCREC –Kade
Vulcano	FOHCREC –Kade
Z-607	FOHCREC –Kade
Delhi Hot	FOHCREC –Kade
ICPN16#7	FOHCREC –Kade
Salmon Pepper	FOHCREC –Kade
Legon 18	FOHCREC –Kade
Mayford	FOHCREC –Kade
Local Hot Chili	FOHCREC –Kade
Pari Mild	FOHCREC –Kade
9H	PGRRI-Bunso
9A	PGRRI-Bunso
9B	PGRRI-Bunso
7E	PGRRI-Bunso
9F	PGRRI-Bunso
7A	PGRRI-Bunso

3.4 Field and Greenhouse Experiments

Morphological characterization was done on the pepper genotypes both under Greenhouse and Field conditions based on the standard descriptors for Capsicum species (IPGRI, AVRDC, CATIE, 1995).

3.5 Details of the Experiment

The experiment was conducted concurrently in two locations (Greenhouse and the Field) at FOHCREC, Kade; from November, 2014 to April, 2015.

3.5.1 Experimental Design

Both experiments (under Greenhouse and the Field conditions) were laid out in randomized complete block design. Each of the seventeen (17) genotypes were replicated three (3) times. Therefore, fifty-one (51) plots were used at each environment. To avoid biases, genotypes were assigned to plots randomly using the drawing lots method.

3.5.2 Dimensions of the Experimental Plots and Planting Distances under Greenhouse and Field Conditions

Under field conditions, the plants were sown on six (6) ridges which had been planted to okra in the previous season. The length of each of the six (6) ridges used was 82.6 m with a width of 0.53 m. The ridges were 0.7 m apart. The planting distance was 0.8 m × 0.59 m. Under greenhouse conditions, six (6) beds were used. The length of each bed was 6 m with a width of 0.95 m. A distance of 0.54 m separated the beds. The planting distance was 0.6 m × 0.5 m.

3.6 Nursery and Cultural Practices

3.6.1 Sowing of Seeds, Raising Seedlings and Transplanting

The seeds were sown in compartmentalized seed boxes filled with rice biochar (carbonated rice husk) medium with two seeds per cell. Regular watering was done after germination until transplanting. N.P.K 19:19:19 (poly-feed) was applied as foliar fertilizer at a concentration of 5.33 g/L two (2) weeks after germination. To prevent damping-off disease at the nursery, the

seedlings were sprayed with the fungicide Top Cop, at the concentration of 10 ml/L at two (2) weeks intervals. Seedlings were transplanted four (4) weeks after sowing.

3.6.2 Weed Control, Fertilizer and Pesticide Applications

Manual weeding was done both under greenhouse and field conditions as necessary. During the vegetative stage, N.P.K 19:19:19 (poly-feed) at a concentration of 5.7 g/L was applied (foliar application) at two (2) weeks intervals. Multi-K brand of N.P.K fertilizer was applied at a concentration of 8 g/L for two conservative times at two weeks intervals just before flower initation and two weeks after flower initiation. Insect pests and fungal diseases were controlled with Cuprofix (fungicide) at a concentration of 3 g/L and brand Cyperdem (insecticide) at a concentration of 2.33 ml/L.

3.7 Data Collection on Morphological Traits

Data were collected at vegetative, flowering and fruiting stages. All data collection was based on the descriptors for *Capsicum* species (IPGRI, AVRDC, CATIE, 1995). Five (5) plants per plot were tagged for data taking.

3.7.1 Quantitative Characters

The data were collected on each of five record plants per genotype and the means computed for the following quantitative characters:

3.7.1.1 Mean Plant Height (cm)

Plant height was measured at first harvest. Measurement was taken from the base of the plant to the terminal with a meter rule in centimeters (cm). For each genotype, measurement were taken on the five (5) record plants and the mean calculated.

3.7.1. 2 Mean Plant Canopy Width (cm)

The width of the canopy was measured immediately after the first harvest with a meter rule in centimeters (cm). Measurement were taken at the widest point of the canopy. For each genotype, measurements were taken on the five (5) record plants and the mean determined.

3.7.1.3 Mean Stem Girth (cm)

Stem girth was measured three (3) centimeters above the ground with vernier calipers immediately after the first harvest. For each genotype, measurements were taken on the five (5) record plants and the mean calculated.

3.7.1.4 Days to 50% Flowering

The number of days to 50% flowering was taken from the day after transplanting to the date when 50% of plants per plot had at least one open flower. The average of the three (3) replicated plots for each genotype was taken to represent the value for the genotype.

3.7.1.5 Mean Days to Fruiting

Total days to fruiting was recorded as the number of days after transplanting until 50% of plants per plot have mature fruits at the first and second bifurcation. The average number of days was found for each genotype in the three (3) replicated plots to represent the value for the genotype.

3.7.1.6 Mean Fruit Length (cm)

Ten (10) fruits per genotype were sampled at the second harvest from each plot and the length measured with a ruler in centimeters (cm). The average was taken for the fruit length of the genotype.

3.7.1.7 Mean Fruit Width (cm)

Ten (10) fruits were sampled from the second harvest in each genotype per plot. Their widths were taken at the widest diameter with a caliper (in centimeters). The mean for each genotype was taken as the width of that genotype.

3.7.1.8 Mean Fruit Wall Thickness (mm)

Ten (10) fruits from each genotype were sampled at the second harvest per plot. The wall thickness (in millimeter) was measured on ten (10) fruits per genotype at the point of maximum width with vernier calipers. The mean was then calculated.

3.7.1.9 Mean Yield per Hectare (ton/ha)

The total yield per hectare was calculated based on the formula below;

$$Yield(ton/ha) = \frac{Area\,of\,a\,hectare}{Area\,of\,plot} \times Yield\,per\,plot$$

3.7.1.10 Mean Number of Leaves

The total number of leaves was counted in the five tagged plants per plot in each genotype at harvest for each replication. The average was taken for each genotype.

3.7.1.11 Mean Number of Seeds per Fruit

Ten (10) fruits were randomly selected from each genotype. The seeds were extracted and counted and the average was taken to represent the number of seeds for the genotype.

3.7.1.12 Mean Chlorophyll Content

The chlorophyll meter was used to measure the chlorophyll content of five (5) plants per plot at both flowering and harvest stages. The average was taken for each genotype.

3.8 Laboratory Analysis of Fruit Quality Traits

Laboratory work was carried out on six (6) phytochemical characters of the pepper genotypes. These included phenolic acids (gallic, vanillic, and rosmarinic acids), total flavonoids, lycopene and β-carotene contents as well as antioxidant activities (IC_{50} value). Dried and ground fruit samples of all the pepper genotypes were used for the phytochemical analysis.

3.8.1 Drying of Pepper Genotypes

Fully ripe fruits were used for the chemical analysis. Unquantified sample of ripe fruits was oven-dried at 60^{o}C for forty-eight (48) hours as described by Ikpeme *et al.* (2014).

3.8.2 Preparation of Pepper Samples

Pepper samples were prepared with a modified approach by Tsai *et al.* (2009). The pepper fruits were pulverized into fine powder. Ten (10) grams of the pulverized samples was extracted with 100 ml of methanol at 25 ^{o}C at 20xg for 24 hours and filtered through Whatman No. 1 filter paper. The residue was extracted with two additional 100 ml portions of methanol as described above and combined ethanolic extracts were concentrated under reduced pressure below 40 ^{o}C to obtain the crude extract. The crude extracts were re-dissolved in methanol at concentration of 20 mg/ml and stored at 4 ^{o}C for further analyses.

3.8.3 Determination of Total Phenolic Content

Total phenolic content was determined by using Folin-Ciocalteau reagent based on modified version of the method by Harborne (1989). Each sample (1ml) was added to 1 ml aqueous sodium carbonate solution. A volume of 1 ml Folin-Ciocalteau reagent was added to the mixture and topped up to 10 ml. The mixture was agitated and allowed to stand for 90 minutes. The absorbance was measured at 765 nm by using UV/visible spectrophotometer (SpectraMax Plus 384, United states). The concentration of the total phenolic compounds was calculated based on standard curve of gallic acid (0.2 – 1.0 mg/ml) with the linear equation, $y = 0.624x – 0.939$, where $R^2 = 0.995$. The results were expressed as mg of gallic acid equivalent (GAE/mg)

per 100 ml of the extract. For the determination of the concentrations of individual phenolic compounds, the following formulae were used: (a) gallic acid (mg/100ml): y = 0.0871x – 0. 102 (b) vanillic acid (mg/100ml): y = 0.053x + 0.012 (c) rosmarinic acid (mg/100ml): y = 0.069x + 0.022.

3.8.4 Determination of Lycopene and β-Carotene Contents

The modified method of Sharoba (2009) was followed for this determination. To determine the concentrations of lycopene and β-carotene, the absorbances of the extracts were measured at the wavelengths 453nm, 505nm, and 663 by using spectrophotometer (SpectraMax Plus 384, United states). The following formulae according to Nagata and Yamashita (1992) were used to calculate for the concentration of lycopene and β-carotene respectively; a) Lycopene (mg/100ml) = -0.0458A663 + 0.372A505- 0.0806A453 b) β-carotene (mg/100ml) = 0.216A663 – 0.304A505 + 0.452A453.

3.8.5 Determination of Total Flavonoid Content of Pepper Genotypes

The modified aluminum chloride colorimetric method by Barros *et al*. (2007) was used to determine the flavonoid content. Methanolic extract of pepper fruits (0.5 ml) was mixed with distilled water at 500 µl and sodium nitrite, $NaNO_2$ (5%, 30 µl). Mixture was allowed to stand for 5 minutes. Aluminum chloride solution, $AlCl_3.H_2O$ (10%, 60 µl) was added to the mixture. The mixture was allowed to stand for 6 minutes. Sodium hydroxide, NaOH (1M, 200 µl) and distilled water of 110 µl were added to the mixture and thoroughly mixed. Absorbance was taken at 510 nm (SpectraMax Plus 384, United States). Concentration of total flavonoid content was computed based on standard curve of rutin (0.2 – 1.0 mg/ml) with the linear equation y= 0.0101x + 0. 2238 with R^2 = 0.9563. The results were expressed as mg of rutin equivalent (RE/mg) 100 ml of the extract.

3.8.6 Determination of Antioxidant Activity of Genotypes

3.8.6.1 Chemicals and Reagents

The chemical DPPH was secured from Sigma Aldrich Co. (St. Louis, USA). Other chemicals used were of analytical grade.

3.8.6.2 2, 2-Diphenyl-1-picryhydrazyl (DPPH) Free Radical Scavenging Activity of Methanolic Extract

Diluted working solutions of the test extracts were prepared in methanol. The standard used was ascorbic acid. A volume of 100 µl of test samples (0.6-20 mg/ml) measured accurately in methanol was added to 5 µl DPPH solution. A percentage of 0.002 DPPH was made in methanol. A microliter of the DPPH solution was mixed with 1 ml of sample solution and a standard solution to be tested separately. The solution mixture were kept in the dark for 30 minutes. After that, an optical density was measured at 517 nm by a spectrophotometer against 1 ml methanol as the blank in 1 ml of DPPH solution (0.002%). The optical density was recorded and percentage inhibition was calculated using the formula by (El-Agbar *et al*., 2008).

The percentage inhibition of DPPH activity = $\left(A - B \,/\, A \right)$ where,

A- Optical density of the blank

B- Optical density of the sample.

3.8.6.3 Statistics and Estimation of IC_{50}

The development (decolorization) was plotted against sample extract concentration. A linear regression curve was established for the calculation of IC_{50} (µg/ml). IC_{50} indicates the value of the sample needed to reduce the absorbance of the DPPH radical by 50%.

All phytochemical analysis was carried out in triplicate and the averages were estimated.

3.9 Analysis of Data

All data from the experiments were analyzed by using the GenStat Computer Statistical Software (2009) and XLSTAT statistical software (2015).

3.10 Determination of Heritability and Variance Components of Traits among Genotypes

XLSTAT statistical software package (2015) was used to compute heritability and the variance components.

3.11 Estimation of Heritability and Variance Components of Traits among Genotypes under Individual Environment/Location

The formulae indicated in Table 5 were used to calculate broad sense heritability and variance components for individual environment. The components genotypic coefficient of variation, phenotypic coefficient of variation, expected genetic advance, and genetic advance by percentage were computed according to the procedure used by Farshadfar and Estehghari (2014). The components heritability, genotypic variance, and phenotypic variance were also computed by the procedure followed by Allard (1960).

Table 5: Formulae and symbols for computing heritability and variance components for individual environment / location

Component	Symbol	Formula
Heritability	h^2	(σ^2_g/ σ^2_p) *100
Genotypic Variance	σ^2_g	$(Ms_g – Ms_e)/r$
Phenotypic Variance	σ^2_p	$\sigma^2_g + \sigma_e^2$
Environmental Variance	σ_e^2	Ms_e
Genotypic coefficient of Variation	GCV	$(\sqrt{\sigma^2_g} / x)$ *100
Phenotypic coefficient of Variation	PCV	$(\sqrt{\sigma^2_p} / x)$ *100
Expected Genetic Advance	EGA	$k * \sqrt{\sigma^2_p} * h^2$
Genetic Advance by %	GA%	(EGA/x)* 100

Source: Principles of Plant Breeding by R.W. Allard (1960), International Journal of Biosciences: 2014, Vol. 4, No. 12: p. 193-201.

k- Selection intensity = 2.06, MSe = error mean square, MSg = genotypic mean square, x = mean, r = number of replication

3.11.1 Estimation of Variance for the Individual Environment/ Location for Traits among Genotypes

Table 6 shows the format and formulae for analysis of variance in a single/ individual environment/location. The genotypic, environmental and phenotypic variances were computed from mean squares by the method followed by Farshadfar and Estehghari (2014).

Table 6: Analysis of variance for the individual environment /location

Source of variation	Df	MS	EMS	F-test
Replication	*r-1*	MS_r	$\sigma^2_e + g\sigma^2_r$	
Genotype	*g-1*	MS_g	$\sigma^2_e + r\sigma^2_g$	MS_g/MS_e
Error	*(r-1) (g-1)*	MS_e	σ^2_e	
Total	*gr - 1*			

Source: International Journal of Biosciences: 2014, Vol. 4, No. 12: p. 193-201.

l= location/environment, g = number of genotypes used, r = number of replication,

MSr = replication mean square, Ms_g = genotypic mean square, MS_e = error mean square, σ^2_e = environmental variance, $r\sigma^2$ = replication variance

3.12 Estimation of Heritability and Variance Components for the Combined Environment/ Location for Traits among Genotypes

The formulae as indicated in Table 7 were used to calculate broad sense heritability and variance components for the combined environment. The h^2, $\sigma^2 g$, and $\sigma^2 p$ were computed according to the procedure used by Usman (2013). The components EGA and GA% were estimated by the procedure used by Johnson *et al*. (1955) as reported by Idahosa (2010).

Table 7: Formulae and symbols for computing heritability and variance components for the combined environment / location.

Component	Symbol	Formula
Heritability	h^2	$\sigma^2g/ \sigma^2_P = \sigma^2g/ [\sigma^2g + (\sigma^2gl/l) + (\sigma^2e/rl)]$
Genotypic Variance	σ^2_g	(MSg – MSgl)/rl
Phenotypic Variance	σ^2_p	$\sigma^2g + (\sigma^2gl/l) + (\sigma^2e/rl)$
Environmental Variance	σ^2_e	MSe
Genotypic coefficient of variation	GCV	$(\sqrt{\sigma^2g} / x) *100$
Phenotypic coefficient of variation	PCV	$(\sqrt{\sigma^2p} / x) *100$
Expected Genetic Advance	EGA	$k * \sqrt{\sigma^2p} * h^2b$
Genetic Advance by %	GA%	(EGA/X)* 100
Genotype x environment interaction variance	σ^2_gl	$(MS_gl - MS_e)/r$

Source: Academia Arena, 2010: 2(5):22-26, Thesis work of Usman (2013) published at http://ugspace.ug.edu.gh

k- Selection intensity = 2.06, MS_e = error mean square, MS_g = genotypic mean square

MS_gl = genotype * environment mean square, σ^2_gl = genotype * location variance

x = mean, l = environment/location, r = replication

3.12.1 Analysis of Variance for the Combined Environment /Location

Table 8 shows the format and formulae for analysis of variance for the combined environment/location. This format followed the procedure used by Usman (2013).

Table 8: Analysis of variance for the combined environment /location

Source of variation	DF	Mean square	Expected mean square	F-test
Replication (R)	r-1	MS_b		
Replication (Location)	r (l-1)	MSr (l)		
Location (L)	l-1	MSl	$\sigma^2_e + r\sigma^2_{gl} + rg\ \sigma^2_l$	MSl/MS_{ge}
Genotype (G)	g-1	MS_g	$\sigma^2_e + r\sigma^2_{gl} + rl\sigma^2_g$	MSg/MS_e
Genotype x Location	(g-1) (l-1)	MS_{ge}	$\sigma^2_e + r\ \sigma^2_{gl}$	$MSge/MS_e$
Residual	(gl-1) (r-1)	MS_e	σ^2_e	
Total	glr-1			

MS_b = replication Mean square, MSr (l) = Replication * Location mean square, MSl = Location mean square, MS_g = genotype mean square, MS_{ge} = genotype* environment mean square, MS_e = error mean square, σ^2_{gl} = genotype *location variance, σ^2_e = environmental variance, σ^2_g = genotypic variance, σ^2l = location variance = genotype, l = location, r = replication.

3.13 Correlation Coefficient Estimation

The Pearson's correlation coefficient was used to show the association between the agro-morphological and antioxidant traits among the pepper genotypes. The method suggested by Hanson *et al.* (1956) was used as follow;

$$r = \text{cov} \cdot xy / (\text{var} \cdot x)(\text{var} \cdot y)$$

Where; r = correlation coefficient

cov.x y = covariance between trait x and y.

CHAPTER FOUR

4.0 RESULTS

4.1 AGRO-MORPHOLOGICAL TRAITS OF PEPPER GENOTYPES

4.1.1 VEGETATIVE TRAITS OF PEPPER GENOTYPES

4.1.1.1 Mean Plant Height in Pepper Genotypes (cm)

Mean plant height values are presented in Table 9. Under field conditions, genotype 9B recorded the lowest mean value of 34.57 cm while genotype 9A recorded the highest mean value of 65.63 cm about a grand mean of 55.06 cm. Under greenhouse conditions, genotype 9B recorded the lowest mean value of 49.48 cm while genotype Pari Mild recorded the highest mean value of 112.75 cm about a grand mean of 122.19 cm. For the combined analysis, genotype 9B recorded the lowest mean value of 49.48 cm while genotype Pari Mild recorded the highest mean value of 112.75 cm about a grand mean of 88.63 cm. Combined analysis of variance showed highly significant difference ($P < 0.001$) among genotypes, environment and genotype x environment interaction (appendix 6).

4.1.1.2 Mean Canopy Width in Pepper Genotypes (cm)

Mean canopy width values are presented in Table 9. Under field conditions, genotype 9B recorded the least mean value of 20.03 cm while genotype 9A recorded the widest mean value of 64.33 cm about a grand mean of 46.48 cm. Under greenhouse conditions, genotype 9B recorded the least mean value of 29.27 cm while genotype 9H recorded the widest mean value of 131.13 cm about a grand mean of 97.18 cm. For the combined analysis, genotype Legon 18 recorded the least mean value of 29.27 cm while genotype ICPN16#7 recorded the widest mean value of 89.28 cm about a grand mean of 80.53 cm. Combined analysis of variance showed

highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 6).

Table 9: Mean values for plant height and canopy width of 17 pepper genotypes grown under greenhouse and field conditions.

	Plant Height(cm)			Canopy Width(cm)		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	57.20	117.67	87.43	51.50	98.20	74.85
7E	60.93	126.73	93.83	47.47	96.00	71.73
9A	65.63	109.40	87.52	64.33	87.13	75.73
9B	34.57	64.40	49.48	20.03	29.27	24.65
9F	63.43	149.40	106.42	55.5	106.07	74.85
9H	53.17	154.93	104.05	47.43	131.13	71.73
Del H	56.87	156.40	106.63	44.37	44.37	75.73
Gal	57.67	140.33	99.00	40.17	40.17	24.65
GR	64.87	112.07	88.47	55.3	55.3	80.78
ICP	46.27	96.0	71.43	43.63	43.63	89.28
L18	61.23	120.40	90.82	49.37	49.37	93.52
LHC	46.97	138.07	92.52	42.7	42.7	85.22
MF	56.03	110.67	83.35	42.77	97.07	82.45
PM	62.2	163.30	112.75	47.27	113.8	57.42
Sal	59.93	138.40	99.17	55.25	87.6	65.18
Vul	41.13	88.60	64.87	36.5	83.27	71.28
Z-607	48.00	89.80	68.90	46.63	88	69.92
Grand Mean	55.06	122.19	88.63	46.48	97.18	80.53
$LSD_{(0.05)}$	14.33	14.73	9.89	15.55	15.58	10.74

4.1.1.3 Mean Number of Leaves in Pepper Genotypes

Mean number of leaves are presented in Table 10. Under field conditions, genotype Galaxy recorded the lowest mean value of 179 while genotype 9A recorded the highest mean value of 465 about a grand mean of 301. Under greenhouse conditions, genotype Vulcano recorded the

lowest mean value of 135 while genotype Galaxy recorded the highest mean value of 531 about a grand mean of 317. For the combined analysis, genotype Vulcano recorded the lowest mean value of 144 while genotype 9H recorded the highest mean value of 426 about a grand mean of 309. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes and genotype x environment interaction but no significance in environment (appendix 6).

4.1.1.4 Mean Stem Girth in Pepper Genotypes (cm)

Mean stem girth values are presented in Table 10. Under field conditions, genotype Local Hot Chili recorded the lowest mean value 0.45 cm while genotype 9A recorded the highest mean value of 1.1 cm about a grand mean of 0.84 cm. Under greenhouse conditions, genotype 9B recorded the lowest mean value of 0.73 cm while genotype 9F recorded the highest mean value of 2.88 mm about a grand mean of 1.08 cm. For the combined analysis, genotype 9B recorded the lowest mean value of 0.71 cm while genotype 9F recorded the highest mean value of 1.86 cm about a grand mean of 0.96 cm. Combined analysis of variance showed no significant difference in genotypes, environment and genotype x environment interaction (appendix 6**).**

Table 10: Mean values for number of leaves and stem girth of 17 pepper genotypes grown under greenhouse and field conditions.

	Number of Leaves			Stem Girth (cm)		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	281	244	262	0.96	1.04	1
7E	328	226	277	1.06	0.93	0.99
9A	465	285	375	1.1	0.81	0.95
9B	187	275	231	0.69	0.73	0.71
9F	318	497	408	0.85	2.88	1.86
9H	399	453	426	0.96	1.27	1.12
Del H	219	416	318	0.74	1.06	0.9
Gal	179	531	355	0.71	1.04	0.87
GR	317	289	303	0.86	0.89	0.87
ICP	231	267	249	0.76	0.84	0.8
L18	410	277	344	0.99	0.97	0.98
LHC	421	327	374	0.45	0.89	0.67
MF	254	253	254	0.92	0.93	0.93
PM	362	408	385	0.93	0.98	0.95
Sal	434	264	349	0.91	0.86	0.89
Vul	154	135	144	0.68	1.33	1.01
Z-607	165	250	208	0.71	0.87	0.79
Grand M	301	317	309	0.84	1.08	0.96
$LSD_{(0.05)}$	111.2	34.3	57.5	0.248	1.46	0.716

4.2 Chlorophyll Content of Pepper Genotypes

4.2.1 Mean Chlorophyll Content at Flowering Stage in Pepper Genotypes

Mean chlorophyll content values are presented in Table 11. Under field conditions, genotype Local Hot Chili recorded the lowest mean value of 40.8 nm while genotype 7A recorded the highest mean value of 127.6 nm about a grand mean of 75.6 nm. Under greenhouse conditions, genotype Local Hot Chili recorded the lowest mean value of 18.2 while genotype Vulcano recorded the highest mean value of 47 nm about a grand mean of 53.5 nm. For the combined analysis, genotype Local Hot Chili recorded the lowest mean value of 29.5 nm while genotype 7A recorded the highest mean value of 85.3 nm about a grand mean of 53.5 nm. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 6).

4.2.2 Mean Chlorophyll Content at Harvest in Pepper Genotypes

Mean chlorophyll content values are presented in Table 11. Under field conditions, genotype Salmon recorded the lowest mean value of 26.7 nm while genotype GR 202 recorded the highest mean value of 116.3 nm about a grand mean of 56 nm. Under greenhouse conditions, genotype Local Hot Chili recorded the lowest mean value of 21.7 while genotype Vulcano recorded the highest mean value of 96.1 nm about a grand mean of 57.4 nm. For the combined analysis, genotype Salmon pepper recorded the lowest mean value of 25.9 nm while genotype GR 202 recorded the highest mean value of 98.1 nm about a grand mean of 17.35 nm. Combined analysis of variance showed highly significant difference ($P < 0.001$) among genotypes, no significant difference in environment and significant difference ($P = 0.015$) in genotype x environment interaction (appendix 6).

Table 11: Mean values for chlorophyll content at the reproductive and harvest stages of 17 pepper genotypes grown under greenhouse and open field conditions.

	Chlorophyll content at F (nm)			Chlorophyll content at H (nm)		
	Environment			Environment		
Genotype	Field	Green H		Field	Green H	
7A	127.6	43.1	85.3	77.5	93.7	85.6
7E	93.9	36.2	65.1	75.8	76.2	76
9A	65.7	33.7	49.7	29.6	53.8	41.7
9B	71	33.5	52.3	57.1	51.6	54.4
9F	51.6	26.2	38.9	27	33	30
9H	68.2	25.4	46.8	39.8	49.5	44.7
Del H	64.4	25.3	44.8	53.3	57.3	55.3
Gal	80.9	33.2	57	71.1	60.9	66
GR	112.2	42.2	77.2	116.3	79.8	98.1
ICP	63.4	27.6	45.5	54.5	40	47.3
L18	60.6	28.5	44.5	61.3	57.3	59.3
LHC	40.8	18.2	29.5	37.5	21.7	29.6
MF	76.8	30.1	53.5	29.5	54.7	42.1
PM	56.9	22.4	39.6	51.1	34.2	42.7
Sal	52.9	19.2	36	26.7	25	25.9
Vul	96.3	47	71.7	59.7	96.1	77.9
Z-607	102	42.7	72.4	84.2	90.9	87.6
Grand M	75.6	31.4	53.5	56	57.4	56.7
$LSD_{(0.05)}$	16.22	5.61	8.53	31.56	14.12	17.35

F- Flowering Stage, H- Harvest

4.3 REPRODUCTIVE TRAITS OF PEPPER GENOTYPES

4.3.1 Mean Days to 50% Flowering in Pepper Genotypes

Mean days to 50% flowering values are presented in Table 12. Under field conditions, genotype Legon 18 scored the highest mean days of 73 while genotype GR 202 scored the lowest mean days of 28 about a grand mean of 41 days. Under greenhouse conditions, genotype 9H scored the highest mean days of 97 while genotype GR 202 scored the lowest mean days of 28 about a grand mean of 44 days. For the combined analysis, genotype Legon 18 scored the highest mean days of 78 while genotype GR 202 scored the lowest mean days of 28 about a grand mean of 43 days. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, genotype x environment interaction and significance difference in environment ($P = 0.017$) as indicated in appendix 3.

4.3.2 Mean Days to 50% Fruiting in Pepper Genotypes

Mean days to 50% fruiting values are presented in Table 12. Under field conditions, genotype Legon 18 scored the highest mean days of 90 while genotype GR 202 scored the lowest mean days of 48 about a grand mean of 70 days. Under greenhouse conditions, genotype 9H scored the highest mean days of 117 while genotype Vulcano scored the lowest mean days of 46 about a grand mean of 76 days. For the combined analysis, genotype 9H scored the highest mean days of 100 while genotype GR 202 scored the lowest mean days of 49 about a grand mean of 73 days. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment, and genotype x environment interaction (appendix 3).

Table 12: Mean values for number of days to 50% flowering and fruiting of 17 pepper genotypes grown under greenhouse and field conditions.

	Days to 50% flowering			Days to 50% fruiting		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	38	34	36	62	70	66
7E	40	34	37	66	60	63
9A	45	38	41	84	85	85
9B	41	32	36	63	60	62
9F	51	34	42	83	82	82
9H	50	97	73	83	117	100
Del H	33	32	32	64	85	74
Gal	44	71	58	74	91	83
GR	28	28	28	48	49	49
ICP	34	32	33	59	62	61
L18	73	83	78	90	97	94
LHC	48	65	56	85	93	89
MF	32	32	32	64	51	57
PM	43	36	39	83	90	86
Sal	42	39	40	72	100	86
Vul	31	30	31	59	46	53
Z-607	34	32	33	56	55	56
Grand M	41	44	43	70	76	73
$LSD_{(0.05)}$	9.88	6.65	5.87	8.268	7.50	6.07

4.3.3 Mean Days to First Fruit set in Pepper Genotypes

Mean days to first fruit set values are presented in Table 13. Under field conditions, genotype Local Hot Chili scored the highest mean days of 62 while genotype GR 202 scored the lowest mean days of 28 about a grand mean of 41days. Under greenhouse condition, genotype Legon 18 scored the highest mean days of 75 while genotype GR 202 scored the lowest mean days of 27 about a grand mean of 48. For the combined analysis, genotype 9H scored the highest mean days of 65 while genotype GR 202 scored the lowest mean days of 28 about a grand mean of 44 days. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment, and genotype x environment interaction (appendix 3).

4.3.4 Mean Days to Ripening in Pepper Genotypes

Mean days to ripening value are presented in Table 13. Under field conditions, genotype Salmon pepper scored the highest mean days of 87 while genotype Z-607 scored the lowest mean days of 56 about a grand mean of days 73. Under greenhouse conditions, genotype 9H scored the highest mean days of 108 while genotype Z-607 scored the lowest mean days of 57 about a grand mean of 84 days. For the combined analysis, genotype 9H scored the highest mean days of 47 while genotype GR 202 recorded the lowest mean days of 57 about a grand mean of 79 days. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes and environment, and significant difference ($P = 0.03$) in genotype x environment interaction (appendix 3).

Table 13: Mean values for days to first fruit set and ripening of 17 pepper genotypes grown under greenhouse and field conditions.

	Days to first fruit set			Days to ripening		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	39	42	40	80	86	83
7E	43	46	44	73	80	77
9A	47	49	48	80	85	83
9B	40	40	40	76	72	74
9F	47	53	50	72	86	79
9H	49	81	65	85	108	97
Del H	32	41	37	64	89	76
Gal	44	66	55	79	96	88
GR	28	27	28	66	77	71
ICP	30	38	34	67	79	73
L18	46	75	61	81	93	87
LHC	62	68	65	81	103	92
MF	31	28	30	61	68	65
PM	47	40	44	73	81	77
Sal	46	57	52	87	102	95
Vul	32	33	33	65	69	67
Z-607	29	32	31	56	57	57
Grand M	41	48	44	73	84	79
$LSD_{(0.05)}$	12.96	11.19	8.37	9.678	12.45	7.87

4.4 FRUIT QUALITY TRAITS OF PEPPER GENOTYPES

4.4.1 Mean Fruit Length of Pepper Genotypes (cm)

Mean fruit length values are presented in Table 14. Under field condition, genotypes 9F and 9A recorded same value of 2.4 cm as the shortest mean while genotype ICPN16#7 recorded the longest mean value of 10.4 cm about a grand mean of 5.7 cm. Under greenhouse condition, genotypes Salmon pepper and 9A recorded the same value of 2.4 cm as shortest means while genotype ICPN16#7 recorded mean of 17.1 cm about a grand mean of 9 cm. For the combined analysis, genotype 9A recorded the shortest mean of 2.4 cm while genotype ICPN16#7 recorded the mean of 13.8 cm about a grand mean of 7.3 cm. Combined analysis of variation showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 3).

4.4.2 Mean Fruit width of Pepper Genotypes (cm)

Mean fruit width values are presented in Table 14. Under field conditions, genotype Mayford recorded the lowest mean value of 0.55 cm while genotype ICPN16#7 recorded the highest mean value of 1.46 cm about a grand mean of 1.00 cm. Under greenhouse conditions, genotype Local Hot Chili recorded lowest mean value of 0.62 cm while genotype ICPN16#7recorded the highest mean value of 2.24 cm about a grand mean of 1.4 cm. For the combined analysis, genotype Local Hot Chili recorded the lowest mean of 0.6 cm while genotype ICPN16#7 recorded the highest mean of 1.9 cm about a grand mean of 1.2 cm. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 3).

Table 14: Mean values for fruit length and fruit width of 17 pepper genotypes grown under greenhouse and field conditions.

	Fruit Length (cm)			Fruit Width (mm)		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	9.1	12.5	10.8	0.99	1.38	1.185
7E	6.7	11.8	9.25	0.96	1.35	1.155
9A	2.4	2.4	2.4	1.43	1.33	1.38
9B	2.9	5.9	4.4	0.63	0.74	0.7
9F	2.4	3	2.7	1.2	2.03	1.615
9H	6.9	8.9	7.9	0.95	0.85	0.9
Del H	7.8	12.7	10.25	0.8	1.63	1.215
Gal	6.1	9.8	8	1.03	1.68	1
GR	8.1	14.5	11.3	1.21	1.64	1.4
ICP	10.4	17.1	13.8	1.46	2.24	1.9
L18	5.6	8.4	7.0	0.95	0.97	1.0
LHC	3.3	2.8	3.1	0.49	0.62	0.6
MF	7.3	10	8.7	0.55	1.69	1.1
PM	2.5	4.2	3.4	1.2	1.63	1.4
Sal	2.8	2.4	2.6	1.43	0.87	1.2
Vul	5	12.9	9.0	1.06	2.03	1.5
Z-607	7	13.6	10.3	0.94	1.22	1.1
Grand M	5.7	9.0	7.3	1.0	1.4	1.2
$LSD_{(0.05)}$	1.04	1.48	0.96	0.33	0.58	0.33

4.4.3 Mean Fruit Wall Thickness of Pepper Genotypes (mm)

Mean fruit wall thickness values are presented in Table 15. Under field conditions, genotype Vulcano recorded the lowest mean value of 0.03 mm while genotype 9B recorded the highest mean value of 0.65 mm about a grand mean of 0.17 mm. Under greenhouse conditions, genotype Local Hot Chili recorded lowest mean value of 0.05 mm while genotype Legon 18 recorded the highest mean value of 0.31 mm about a grand mean of 0.19 mm. For the combined analysis, genotype Local Hot Chili recorded the lowest mean of 0.06 mm while genotype 9B recorded the highest mean of 0.39 mm about a grand mean of 0.18 mm. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes and genotype x environment interaction but no significant difference in environment (appendix 3).

4.4.4 Mean Number of Seeds per Fruit in Pepper Genotypes

Mean number of seeds per fruit are presented in Table 15. Under field conditions, genotype 9B recorded the lowest mean value of 26 while genotype ICPN16#7 recorded the highest mean value of 69 about a grand mean of 48. Under greenhouse conditions, genotype Pari Mild recorded lowest mean value of 20 while genotype ICPN16#7 recorded the highest mean value of 100 about a grand mean of 57. For the combined analysis, genotype Pari Mild recorded the lowest mean value of 26 while genotype ICPN16#7 recorded the highest mean value of 85 about a grand mean of 53. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 3).

Table 15: Mean values for fruit wall thickness and number of seeds per fruit of 17 pepper genotypes grown under greenhouse and field conditions.

	FWT(cm)			Number of Seeds per Fruit		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	0.12	0.21	0.17	68	87	78
7E	0.25	0.24	0.25	58	65	62
9A	0.11	0.06	0.09	39	22	31
9B	0.65	0.12	0.39	26	47	37
9F	0.07	0.06	0.07	36	38	37
9H	0.12	0.20	0.16	42	56	49
Del H	0.12	0.18	0.15	67	73	70
Gal	0.29	0.27	0.28	67	97	82
GR	0.19	0.23	0.21	54	62	58
ICP	0.17	0.28	0.23	69	100	85
L18	0.11	0.31	0.21	61	71	66
LHC	0.06	0.05	0.06	33	31	32
MF	0.11	0.14	0.13	28	83	56
PM	0.12	0.40	0.26	31	20	26
Sal	0.11	0.09	0.10	30	34	32
Vul	0.03	0.24	0.14	56	38	47
Z-607	0.27	0.07	0.17	58	41	50
Grand M	0.17	0.19	0.18	48	57	53
$LSD_{(0.05)}$	0.052	0.212	0.11	9.5	7.53	6.1

FWT- fruit wall thickness

4.5 YIELD QUALITY TRAITS RECORDED ON PEPPER GENOTYPES

4.5.1 Mean Number of Fruits per Plant in Pepper Genotypes

Mean number of fruit per plant values are presented in Table 16. Under field conditions, genotype ICPN16#7 recorded the lowest mean number of 29 while genotype 9A recorded the highest mean value of 180 about a grand mean of 77. Under greenhouse conditions, genotype 7E recorded lowest mean value of 36 while genotype 9F recorded the highest mean value of 152 about a grand mean of 81. For the combined analysis, genotype ICPN16#7 recorded the lowest mean value of 35 while genotype 9F recorded the highest mean value of 152 about a grand mean of 79. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, but no significant difference in environment and genotype x environment interaction (appendix 6).

4.5.2 Mean Yield (tons/ha) in Pepper Genotypes

Mean yield (tons/ha) values are presented in Table 16. Under field conditions, genotype 9B recorded the lowest mean value of 0.9 tons/ha while genotype ICPN16#7 recorded the highest mean value of 5.4 tons/ha about a grand mean of 2.9 ton/ha. Under greenhouse conditions, genotype 9A recorded lowest mean value of 1.5 tons/ha while genotype ICPN16#7 recorded the highest mean value of 23 tons/ha about a grand mean of 9.6 tons/ha. For the combined analysis, genotype Local Hot Chili recorded the lowest mean value of 1.5 tons/ha while genotype ICPN16#7 recorded the highest mean value of 14.2 tons/ha about a grand mean of 6.2 tons/ha. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 6).

Table 16: Mean values for yield and number of fruits per plant of 17 pepper genotypes grown under greenhouse and field conditions.

	Number of Fruit per Plant			Yield (tons/ha)		
	Environment			Environment		
	Field	Green H	Mean	Field	Green H	Mean
Genotype						
7A	51	67	59	4.2	17.1	10.7
7E	35	36	36	2.7	6.3	4.5
9A	180	63	122	4.5	1.5	3.0
9B	52	72	62	0.9	3.2	2.1
9F	152	152	152	2.7	5.5	4.1
9H	40	60	50	1.8	5.2	3.5
Del H	45	112	79	2.5	17.3	9.9
Gal	32	94	63	3.5	19.4	11.4
GR	46	80	63	3.9	14.4	9.1
ICP	29	41	35	5.4	23.0	14.2
L18	76	83	80	4.8	8.3	6.5
LHC	136	135	136	1.2	1.8	1.5
MF	38	52	45	1.7	9.3	5.5
PM	161	107	134	2.6	3.6	3.1
Sal	161	101	131	2.2	4.0	3.1
Vul	32	46	39	2.3	10.0	6.2
Z-607	51	83	67	2.9	12.7	7.8
Grand M	77	81	79	2.9	9.6	6.2
$LSD_{(0.05);}$	102.5	34.7	53.1	2.74	4.100	2.48

4.6 POLYPHENOLIC CONTENT AND ANTIOXIDANT PROPERTIES OF PEPPER GENOTYPES

4.6.1 Mean Content of Phenolic Acids in Pepper Genotypes (mg/100 ml)

Mean concentrations of gallic, vanillic and rosmarinic acids are presented in Table 17.

For gallic acid under field conditions, genotype Galaxy recorded the lowest mean value of 9.5 mg/100 ml while genotype 9F recorded the highest mean value of 18.5 mg/100 ml about a grand mean of 13.7 mg/100 ml. Under greenhouse conditions, genotypes ICPN16#7 and Galaxy recorded the same concentration of 7.8 mg/100 ml as lowest mean value while genotype Pari Mild recorded the highest mean value of 18.8 mg/100 ml about a grand mean of 11.4 mg/100 ml. For the combined analysis, genotype Galaxy recorded 8.6 mg/100 ml as the lowest mean value while genotypes Mayford and 9F recorded same concentration of 15.1 mg/100 ml as highest mean value about a grand mean of 12.5 mg/100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 9).

For vanillic acid under field conditions, genotype Pari Mild recorded the lowest mean value of 8.3 mg/100 ml while genotype 9F recorded the highest mean value of 28.8 mg/100 ml about a grand mean of 20.5 mg/100 ml. Under greenhouse conditions, genotypes ICPN16#7 and Galaxy recorded the same concentration of 10.7 mg/100 ml as lowest mean value while genotype Pari Mild recorded the highest mean value of 18.8 mg/100 ml about a grand mean of 16.6 mg/100 ml. For the combined analysis, genotype Galaxy recorded the lowest mean value of 12.1 mg/100 ml while genotype 9F recorded the highest mean value of 22.9 mg/100 ml about a grand mean of 18.6 mg/100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 9).

For rosmarinic acid under field conditions, genotype Pari Mild recorded the lowest mean value of 6.5 mg/100 ml while genotype 9F recorded the highest mean value of 22 mg/100 ml about a grand mean of 15.7 mg/100 ml. Under greenhouse conditions, genotypes ICPN16#7 and Galaxy recorded the same concentration of 8.1 mg/100 ml as lowest mean value while genotype Pari Mild recorded the highest mean value of 21.9 mg/100 ml about a grand mean of 12.6 mg/100 ml. For the combined analysis, genotype Galaxy recorded the lowest mean value of 9.1 mg/100 ml while genotype 9F recorded the highest mean value of 17.5 mg/100 ml about a grand mean of 14.2 mg/100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, environment and genotype x environment interaction (appendix 9).

Table 17: Mean values for gallic, vanillic, and rosmarinic acids of 17 pepper genotypes grown under greenhouse and field conditions.

Genotype	Garlic acid(mg/100 ml)			Vallinic acid(mg/100 ml)			Rosmarinic acid(mg/100 ml)		
	Environment			Environment			Environment		
	Field	Green H	Mean	Field	Green H	Mean	Field	Green H	Mean
7A	11.1	10.1	10.6	16.1	14.5	15.3	12.2	11.0	11.6
7E	13.2	11.5	12.3	20.1	16.7	18.4	15.3	12.7	14.0
9A	16.5	10.4	13.4	24.9	14.9	19.9	19.0	11.3	15.2
9B	15.1	12.7	13.9	22.7	18.8	20.7	17.2	14.3	15.8
9F	18.5	11.7	15.1	28.8	17.1	22.9	22.0	13.0	17.5
9H	12.3	13.1	12.7	18.2	20.0	19.1	13.5	14.7	14.1
Del H	15.7	8.1	11.9	23.6	11.1	17.4	18.0	8.4	13.2
Gal	9.5	7.8	8.6	13.4	10.7	12.1	10.1	8.1	9.1
GR	12.7	8.1	10.4	18.6	11.2	14.9	14.8	8.5	11.6
ICP	15.7	7.8	11.7	23.6	10.7	17.2	18.0	8.1	13.1
L18	13.4	12.1	12.7	20.5	17.3	18.9	15.1	13.4	14.2
LHC	15.8	11.8	13.8	23.7	17.5	20.6	19.4	13.2	16.3
MF	18.3	11.8	15.1	27.9	17.5	22.7	21.3	13.3	17.3
PM	6.7	18.8	12.8	8.3	28.8	18.5	6.5	21.9	14.2
Sal	15.3	8.1	11.7	23.2	11.1	17.2	18.0	8.4	13.2
Vul	9.4	16.3	12.9	13.9	25.4	19.6	10.5	19.4	14.9
Z-607	14.0	12.9	13.4	20.9	19.5	20.2	15.9	14.8	15.4
Grand M	13.7	11.4	12.5	20.5	16.6	18.6	15.7	12.6	14.2
LSD $_{(0.05)}$	1.870	1.81	1.37	1.96	2.42	1.75	2.07	1.71	1.45

4.6.2 Lycopene Content in Genotypes (mg/100 ml)

Mean concentrations of lycopene are presented in Table 18. Under field conditions, genotype Local Hot Chili recorded the lowest mean value of 0.03 mg/100 ml while genotype Mayford recorded the highest mean value of 0.15 mg/100 ml about a grand mean of 0.07 mg/100 ml. Under greenhouse condition, genotype Pari Mild recorded the lowest mean value of 0.05 mg/100 ml while genotype 9F recorded the highest mean value of 0.4 mg/100 ml about a grand mean of 0.16 mg/ 100 ml. For the combined analysis, genotype Hot Chili recorded the lowest mean value of 0.06 mg/100 ml while genotype 9F recorded the highest mean value of 0.23 mg/100 ml about a grand mean of 0.12 mg/ 100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in environment but no significant for genotypes and genotype x environment interaction (appendix 9).

4.6.3 Mean β Carotene Content in Genotypes (mg/100 ml)

Mean concentrations of lycopene are presented in Table 18. Under field conditions, genotypes Local Hot Chili and L18 recorded the lowest mean value of 0.14 mg/100 ml while genotype Vulcano recorded the highest mean value of 0.55 mg/100 ml about a grand mean of 0.28 mg/100 ml. Under greenhouse conditions, genotype Salmon pepper recorded the lowest mean value of 0.03 mg/100 ml while genotype Delhi Hot recorded the highest mean value of 0.7 mg/100 ml about a grand mean of 0.20 mg/100 ml. For the combined analysis, genotype Local Hot Chili recorded the lowest mean value of 0.10 mg/100 ml while genotype Delhi Hot recorded the highest mean value of 0.5 mg/100 ml about a grand mean of 0.24 mg/100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes, significant difference in environment ($P = 0.013$) but no significant for genotypes and genotype x environment interaction (appendix 9).

Table 18: Mean values for lycopene and β carotene content of 17 pepper genotypes grown under greenhouse and field conditions.

	Lycopene(mg/100 ml)			β carotene (mg/100 ml)		
	Environment			Environment		
Genotype	Field	Green H	Mean	Field	Green H	Mean
7A	0.09	0.19	0.14	0.37	0.23	0.30
7E	0.06	0.18	0.12	0.27	0.08	0.18
9A	0.05	0.09	0.07	0.23	0.16	0.20
9B	0.05	0.14	0.10	0.24	0.06	0.15
9F	0.05	0.40	0.23	0.21	0.4	0.31
9H	0.07	0.12	0.10	0.24	0.05	0.15
Del H	0.07	0.14	0.11	0.30	0.7	0.50
Gal	0.09	0.11	0.10	0.33	0.06	0.20
GR	0.08	0.22	0.15	0.35	0.26	0.31
ICP	0.05	0.19	0.12	0.26	0.07	0.17
L18	0.04	0.12	0.08	0.14	0.07	0.11
LHC	0.03	0.09	0.06	0.14	0.05	0.10
MF	0.15	0.16	0.16	0.26	0.07	0.17
PM	0.13	0.05	0.09	0.32	0.4	0.36
Sal	0.06	0.12	0.09	0.24	0.03	0.14
Vul	0.11	0.25	0.18	0.55	0.35	0.45
Z-607	0.07	0.18	0.13	0.33	0.34	0.34
Grand M	0.07	0.16	0.12	0.28	0.20	0.24
$LSD_{(0.05)}$	0.018	0.209	0.103	0.106	0.366	0.187

4.6.4 Mean Total Flavonoid Content of Genotypes (RE/mg/100 ml)

Mean concentrations of total flavonoid are presented in Table 19. Under field conditions, genotypes Delhi Hot and GR 202 recorded the same concentration of 0.22 RE/mg/100 ml as the lowest mean value while genotype Pari Mild recorded the highest mean value of 0.79 RE/mg/100 ml about a grand mean of 0.392 RE/mg/100 ml. Under greenhouse conditions, genotype Local Hot Chili recorded the lowest mean value of 0.22 RE/mg/100 ml while genotype ICPN16#7 recorded the highest mean value of 0.65 RE/mg/100 ml about a grand mean of 0.394 RE/mg/100 ml. For the combined analysis, genotypes Legon 18 and Galaxy recorded same concentration of 0.24 RE/mg/100 ml as the lowest mean value while genotype Vulcano recorded the highest mean value of 0.61 RE/mg/100 ml about a grand mean of 0.393 mg/100 ml. Combined analysis of variance showed highly significant difference ($P < 0.001$) in genotypes and genotype x environment interaction but no significant difference in environment (appendix 9).

4.6.5 Mean of Antioxidant Activity in Pepper Genotypes

Mean concentrations of antioxidant activity are presented in Table 19. Under field conditions, genotype 7A recorded the lowest mean value of 0.92 mg/ml while genotype Galaxy recorded the highest mean value of 1.96 mg/ml about a grand mean of 1.29 mg/100 ml. Under greenhouse conditions, genotype 7A recorded the lowest mean value of 0.64 mg/ml while genotype Legon 18 recorded the highest mean value of 1.65 mg/ml about a grand mean of 1.11 mg/100 ml. For the combined analysis, genotype 7A recorded the lowest mean value of 0.78 mg/ml while genotype Salmon Pepper recorded the highest mean value of 1.69 mg/ml about a grand mean of 1.20 mg/100 ml. Combined analysis of variance showed no significant difference (appendix 9).

Table 19: Mean values for total flavonoids and antioxidant activity of 17 pepper genotypes grown under greenhouse and field conditions.

	Total flavonoid (RE/mg/100 ml)			IC_{50} Values (mg/ml)		
Genotype	Field	Greenhouse	Mean	Field	Greenhouse	Mean
7A	0.24	0.42	0.33	0.92	0.64	0.78
7E	0.24	0.33	0.29	1.02	0.90	0.96
9A	0.58	0.49	0.54	1.22	1.60	1.41
9B	0.26	0.26	0.26	1.78	1.24	1.51
9F	0.53	0.51	0.52	1.3	1.04	1.17
9H	0.23	0.31	0.27	1.11	1.30	1.21
Del H	0.22	0.33	0.28	1.03	1.03	1.03
Gal	0.26	0.22	0.24	1.96	0.77	1.37
GR	0.22	0.5	0.36	0.95	1.32	1.14
ICP	0.25	0.65	0.45	1.11	0.99	1.05
L18	0.25	0.23	0.24	1.28	1.65	1.47
LHC	0.45	0.41	0.43	1.25	1.19	1.22
MF	0.68	0.33	0.51	1.43	0.83	1.13
PM	0.79	0.33	0.56	1.09	1.19	1.14
Sal	0.61	0.43	0.52	1.76	1.61	1.69
Vul	0.63	0.59	0.61	1.63	0.90	1.27
Z-607	0.23	0.36	0.30	1.09	0.71	0.90
Grand M	0.392	0.394	0.393	1.29	1.11	1.20
$LSD_{(0.05)}$	0.150	0.099	0.088	*	*	6

***** -not comparable

4.7 BROAD SENSE HERITATABILTY AND VARIANCE COMPONENTS OF TRAITS

4.7.1 Broad Sense Heritability and Variance Components of Quantitative Agro-Morphological Traits of Genotypes

Genetic variability and broad sense heritability were estimated in all the genotypes for all quantitative agro-morphological traits studied. These are presented in Tables 20, 21 and 22 respectively for field, greenhouse, and the combined effect of both environments.

4.7.1.1 Broad Sense Heritability and Variance Components of Quantitative Agro-Morphological Traits of Genotypes under Field Conditions.

Genetic advance by percentage mean ranged from 17.68% to 166.62%. Fruit wall thickness had the highest value of 166.62% while plant height had the least value of 17.68%. Genotypic co-efficient of variation (GCV %) ranged from 11.40% to 82.8 % and phenotypic co-efficient of variation (PCV %) also ranged between 13.89% and 97.08%. Phenotypic coefficient of variation (PCV %) values were higher than genotypic coefficient of variation (GCV %) for all the traits. Heritability values for the traits ranged between 21.49% and 95.26%. Fruit wall thickness (FWT) recorded the highest of 95.26% and the least of 21.49% for yield (ton/ha).

Table 20: Variance components and broad sense heritability of quantitative agro-morphological traits under Field Conditions

Trait	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV (%)	PCV (%)	GA (%)
DTF	24.71	145.313	170.023	85.47	17.16	18.56	32.68
DtF	35.28	98.450	133.730	73.62	23.91	27.87	42.27
FFS	60.74	64.003	124.743	51.31	19.61	27.37	28.93
DFR	33.86	69.817	103.677	67.34	11.40	13.89	19.27
FL	0.393	6.470	6.863	94.27	44.62	45.96	89.26
FW	0.039	0.072	0.112	64.67	26.35	32.76	43.65
FWT	0.001	0.020	0.021	95.26	82.87	84.90	166.62
NOS	32.96	240.107	273.067	87.93	32.28	34.43	62.36
NOF	3801	1787.333	5588.333	31.98	54.91	97.08	63.96
YTH	2.703	0.740	3.443	21.49	29.45	63.54	28.12
SG	0.022	0.020	0.042	46.92	16.70	24.38	23.57
PH	74.27	53.443	127.713	41.85	13.27	20.51	17.68
NOL	4467	8987.333	13454.333	66.80	31.50	38.54	53.03
CW	87.42	62.757	150.177	41.79	17.04	26.35	22.69
CCF	95.17	522.257	617.427	84.59	30.23	32.87	57.27
CCH	360	460.700	820.700	56.14	38.33	51.16	59.16

4.7.1.2 Broad Sense Heritability and Variance Components of Quantitative Agro-Morphological Traits of Genotypes under Greenhouse Conditions

The highest genetic advance by percentage mean was also recorded for yield (ton/ha) with a value of 130.82%. The least value for genetic advance by percentage mean was 27.24% recorded for mean number of days to ripening. Stem girth was non-significant for genetic advance. Genotypic coefficient of variation (GCV %) ranged from 15.30 % to 67.94 % while phenotypic coefficient of variation (PCV %) was from 17.69% to 80.31%. Stem girth was non-significant for genotypic coefficient of variation (GCV %). Phenotypic coefficient of variation

(PCV %) was higher among all the traits than genotypic coefficient of variation (GCV %). For all the traits, heritability ranged from 23.17% to 96.94%. Number of seeds per fruit had the highest value (96.96%) and the least value (23.17%) was recorded for mean fruit wall thickness. Stem girth recorded a non-significant value.

Table 21: Variance components and broad sense heritability of quantitative agro-morphological traits under Greenhouse Conditions.

Trait	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV (%)	PCV (%)	GA (%)
DTF	20.35	429.10	449.45	95.47	27.21	27.85	54.78
DtF	16.00	433.89	449.89	96.44	47.38	48.25	95.86
FFS	45.32	252.91	298.23	84.80	33.15	35.99	62.88
DFR	56.01	165.88	221.89	74.76	15.30	17.69	27.24
FL	0.79	22.40	23.19	96.60	52.58	53.50	106.46
FW	0.12	0.19	0.31	61.28	30.85	39.42	49.75
FWT	0.02	0.00	0.02	23.17	36.87	76.59	36.56
NOS	20.50	649.13	669.63	96.94	44.82	45.53	90.91
NOF	435.50	915.30	1350.80	67.76	37.35	45.37	63.34
YTH	6.08	42.09	48.17	87.38	67.94	72.67	130.82
SG	0.77	0.00	0.75	0.00	0	80.31	0
PH	78.49	732.08	810.57	90.32	22.14	23.30	43.35
NOL	425.00	11154.37	11579.37	96.33	33.32	33.95	67.36
CW	87.72	649.21	736.93	88.10	26.21	27.93	50.68
CCF	11.37	70.61	81.98	86.13	26.74	28.81	51.11
CCH	72.11	518.26	590.37	87.79	39.66	42.33	76.55

4.7.1.3 Broad Sense Heritability and Variance Components of Quantitative Agro-Morphological Traits of Genotypes (combined).

Genetic advance by percentage mean ranged from 0 % to 87.81 %.The highest was recorded in fruit length (FL) with the value 87.81%. The least of 0 % was also recorded in the trait fruit wall thickness. Genotypic coefficient of variation (GCV %) ranged from 10.88 % (for number of leaves per plant) to 45.80% (for fruit length). Genotypic coefficient of variation was negligible for fruit wall thickness. Phenotypic coefficient of variation (PCV %) ranged from 13.78% to 59.47%. Phenotypic co-efficient of variation (GCV %) in all traits was higher than the Genotypic co-efficient of variation (GCV %) reflecting the environmental component of the phenotypic coefficient of variation. Heritability and genetic variability in all traits were determined from the combined result of the greenhouse and the field on quantitative agro-morphological traits of the genotypes. Heritability ranged from 1.20% to 87.20%. Number of days to ripening recorded the highest heritability of 87.20% while the lowest of 1.20% was recorded for stem girth. Heritability was negligible for the trait fruit wall thickness.

Table 22: Variance components and broad sense heritability of quantitative agro-morphological traits (Combined)

Trait	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV (%)	PCV (%)	GA (%)
DTF	27.74	210.442	252.58	83.32	19.82	21.71	37.27
DtF	25.94	159.680	217.20	73.52	29.57	34.49	52.23
FFS	52.83	117.098	146.62	79.87	24.38	27.28	44.89
DFR	46.62	102.692	117.76	87.20	12.87	13.78	24.75
FL	0.70	11.177	12.90	86.62	45.80	49.21	87.81
FW	0.08	0.057	0.11	53.47	19.80	27.07	29.82
FWT	0.01	0	0.01	0	0	47.21	0
NOS	27.68	266.367	359.95	74.00	30.79	35.80	54.57
NOF	2119.00	1052.667	1555.00	67.70	41.07	49.92	69.61
YTH	4.65	4.662	13.77	33.86	34.60	59.47	41.48
SG	0.3864	0.0008	0.06685	1.20	2.957	26.93	0.66
PH	73.81	149.063	283.64	52.55	13.78	19.00	20.57
NOL	2489.00	1129.333	6007.67	18.80	10.88	25.08	9.71
CW	86.84	101.362	243.27	41.67	14.02	21.71	18.64
CCF	54.78	182.597	248.39	73.51	25.26	29.46	44.61
CCH	226.70	399.133	480.32	83.10	35.24	38.65	66.17

4.7.2 Broad Sense Heritability and Variance Components for phytochemical Traits and IC_{50} for the Genotypes

Broad sense heritability and genetic variability were estimated in all genotypes for antioxidant properties studied. These are presented in Table 23, 24 and 25 respectively for field, greenhouse, and the combined effect of both environments (combined).

4.7.2.1 Broad Sense Heritability and Variance Components for Phytochemical Traits and IC_{50} for the Genotypes under Field Conditions

Genetic advance by percentage mean ranged from 0.00% to 23.18%. Total flavonoid (Flavonoid) had the highest of 23.18% while the least of 0.00% was in IC_{50}. Genotypic coefficient of variation (GCV %) ranged from 22.86% to 49.33%. Phenotypic co-efficient of variation (PCV %) ranged from 24.29% to 54.50%. Phenotypic co-efficient of variation (PCV %) were higher than genotypic co-efficient of variation (GCV %) except in IC_{50} where both parameters had the same value (24.43% in each case). Heritability for phytochemical traits under field conditions ranged from 65.34% to 100%. The IC_{50} value was the highest while heritability for β carotene was 65.3%, the lowest.

Table 23: Variance components and broad sense heritability for phytochemical traits and IC_{50} of genotypes under field conditions

Traits	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV	PCV	GA (%)
BC	0.004	0.008	0.012	65.34	31.35	38.79	22.83
LC	0.000	0.001	0.001	89.25	45.16	47.80	15.67
FC	0.008	0.037	0.045	81.92	49.33	54.50	23.18
IC_{50}	0.000	0.099	0.099	100.00	24.43	24.43	50.25
VA	1.392	28.159	29.551	95.29	25.89	26.52	5.76
GA	1.264	9.822	11.086	88.60	22.86	24.29	8.20
RA	1.556	16.642	18.198	91.45	25.98	27.17	7.95

4.7.2.2 Broad Sense Heritability and Variance Components for Phytochemical traits and IC_{50} of Genotypes under Greenhouse Conditions

The genetic advance by percentage mean varied from 9.83 % (lycopene) to 73.82% (β carotene). The genotypic coefficient of variation (GCV) ranged from 19.63% to 68.08% while the phenotypic coefficient of variation (PCV) was from 27.88% to 129.33%. The phenotypic coefficient of variation (PCV %) was higher for the phytochemical traits except IC_{50} value which was 28.32% in both cases. Heritability among the antioxidants ranged from 5.91% to 100%. The highest of 100% was recorded in IC_{50} value while the least value of 5.91% was in Lycopene content.

Table 24: Variance components and broad sense heritability for phytochemical traits and IC_{50} of genotypes under Greenhouse conditions

Traits	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV (%)	PCV (%)	GA (%)
BC	0.048	0.019	0.067	27.71	68.08	129.33	73.82
LC	0.016	0.001	0.017	5.91	19.63	80.78	9.83
FC	0.004	0.014	0.017	79.45	30.01	33.66	55.10
IC_{50}	0.000	0.099	0.099	100.00	28.32	28.32	58.33
VA	2.111	25.429	27.540	92.33	30.32	31.56	60.02
GA	1.181	8.848	10.029	88.22	26.18	27.88	50.66
RA	1.058	14.887	15.945	93.36	30.62	31.69	60.95

4.7.2.3 Broad Sense Heritability and Variance Components for Phytochemical Traits and IC_{50} in Genotypes (combined)

Genetic advance by percentage mean ranged from 6.79 % to 52.18%. β carotene (B caro) had the highest and IC_{50} the lowest with 52.18% and 6.79% respectively. Genetic advance by percentage was non-significant in vanillic, gallic and rosmarinic acids. Genotypic co-efficient of variation (GCV %) showed non-significant values in lycopene, vanillic, gallic and rosmarinic acids. The lowest value recorded was 7.99% (IC_{50}) and the highest 35.71% (β carotene). For phenotypic co-efficient of variation, the highest of 50.36% (β carotene) was recorded and the least was 13.20% (gallic acid). The phenotypic coefficient of variation (PCV %) had higher values than the genotypic co-efficient of variation (GCV %). Heritability and genetic variability for all the antioxidant constituents were determined from the combined data under greenhouse and field conditions. Heritability ranged from 17.00% to 50.30%. The highest occurred for β carotene and the lowest for IC_{50}. Vanillic, gallic and rosmarinic acids had non-significant heritability.

Table 25: Variance components and broad sense heritability for phytochemical traits and IC_{50} of genotypes (Combined)

Traits	σ^2_e	σ^2_g	σ^2_p	h^2 (%)	GCV (%)	PCV (%)	GA (%)
BC	0.026	0.007	0.015	50.30	35.71	50.36	52.18
LC	0.008	0	0.002	0	0	34.66	0
FC	0.006	0.006	0.016	34.16	19.23	32.90	23.15
IC_{50}	0	0.009	0.054	17.00	7.99	19.39	6.79
VA	2.305	0	7.677	0	0	14.93	0
GA	1.418	0	2.735	0	0	13.20	0
RA	1.583	0	4.534	0	0	15.05	0

4.8 ESTIMATION OF CORRELATION COEFFICIENT AMONG PEPPER GENOTYPES

4.8.1 Estimation of Correlation Coefficient among Pepper Genotypes under Field Conditions

The results for estimates of correlation coefficients for twelve traits among the pepper genotypes under field condition are presented in Table 26. There was highly significant and positive correlation between number of days to 50% flowering (0.764) and number of days to 50% fruiting. Positive and highly significant correlation was observed between days to first fruit ripe (0.526) and days to 50% flowering as well as with days to 50% fruiting (0.570). Days to first fruit set had high significant and positive correlation with days to 50% flowering (0.561), days to 50% fruiting (0.703), and days to first fruit ripe (0.627). Fruit length had a significant and positive correlation with days to 50% flowering (0.332), days to 50% fruiting

(0.483), days to first fruit ripe (0.287) but was significant and negatively correlated with days to first fruit set (-0.475). Lycopene content of pepper genotypes was significant and positively correlated with days to 50% fruiting (0.368**)** but negatively correlated with gallic acid content (-0.290). Antioxidant activity (IC_{50}) value was observed to be significant and negatively correlated with fruit length (-0.424). Total flavonoid content showed significant and positive correlation with lycopene content (0.453), days to 50% fruiting (0.296) but negatively associated with fruit length (-0.545). Number of fruits per plant showed significant and positive association with total flavonoid content (0.422), days to 50% flowering (0.394), days to first fruit set (0.350), days to first fruit ripe (0.337), fruit width (0.321) but negatively correlated with fruit length (-0.567). There was significant and a positive correlation between yield (tons/ha) and fruit width (0.469), number of fruits per plant (0.364), and fruit length (0.281).

Under field conditions, correlations for most of the traits studied were significant but they ranged from low (0.281) to moderate (0.627). However, a few showed strong correlations (from 0.703 to 0.764).

Table 26: Estimates of Correlation Coefficients of Twelve Traits in Pepper Genotypes under Field Conditions

Variables	DtF	DTF	DFR	FFS	FL	FW	GA	LC	IC50	FC	NOF	YTH
DtF	-											
DTF	**0.764**											
DFR	**0.526**	**0.57**										
FFS	**0.561**	**0.703**	**0.627**									
FL	**-0.332**	**-0.483**	**-0.287**	**-0.475**								
FW	0.007	0.011	0.257	0.132	0.004							
GA	0.004	0.055	0.045	0.064	0.007	0.067						
LC	**-0.368**	0.186	0.237	0.275	0.174	0.016						
IC50	0.107	0.109	0.234	0.132	**-0.424**	0.058	0.006	0.062				
FC	0.022	**0.296**	0.04	0.172	**-0.545**	0.165	0.019	**0.453**	0.249			
NOF	0.241	**0.394**	**0.337**	**0.35**	**-0.567**	**0.321**	0.138	0.092	0.029	**0.422**		
YTH	0.098	0.064	0.041	0.214	**0.281**	**0.469**	0.007	0.087	0.237	-0.164	**0.364**	-

Values in bold are different from 0 at the 0.05 level of significance. DtF = days to 50 % flowering, DTF = days to 50% fruiting, DFR = days to first fruit ripe, FFS= days to first fruit set, FL = fruit length, FW= fruit width, GA = gallic acid content, LC = lycopene content, IC_{50} value, FC = total flavonoid content, NOF = number of fruits, YTH = yield (ton/ha)

4.8.2 Estimation of Correlation Coefficients among Pepper Genotypes under Greenhouse Conditions

The results for estimates of correlation coefficients among twelve traits in the pepper genotypes under greenhouse conditions are presented in Table 27. Positive and highly significant correlation was observed between days to 50% fruiting and days to 50% flowering (0.722). Days to first fruit ripe showed highly significant and positive correlation with days to 50% flowering (0.641) and fruiting (0.808). There was highly significant and positive association between first fruit set and days to 50% flowering (0.857), days to 50% fruiting (0.827) and days to first fruit ripe (0.708). Fruit length was significant and positively correlated with days to 50% fruiting (0.553), days to first fruit ripe (0.404) but negatively associated with days to first fruit set (-0.428). Positive and significant association was observed between fruit width and days to 50% flowering (0.423), days to 50% fruiting (0.371), fruit length (0.397), days to first fruit ripe (0.397) but negatively correlated with first fruit set (-0.404). Lycopene content was significant and positively correlated with days to 50 % fruiting (0.286). Antioxidant activity (IC_{50} value) was observed to be significant and positively associated with days to 50% flowering (0.315), days to 50% fruiting (0.504), days to first fruit ripe (0.420), days to first fruit set (0.409), but negatively associated with fruit length (-0.551), and fruit width (-0.391). Total flavonoid content showed positive and significant correlation with days to 50 % flowering (0.446), fruit width (0.467), days to 50% fruiting (0.467) but negatively correlated with days to first fruit set (-0.348). There was positive and significant association for number of fruits per plant and days to 50% fruiting (0.390), days to first fruit ripe (0.321) but negatively associated with fruit length (-0.466).

Table 27: Estimates of Correlation Coefficients of Twelve Traits in Pepper Genotypes under Greenhouse Conditions

Variables	DtF	DTF	DFR	FFS	FL	FW	GA	LC	IC50	FC	NOF	YTH
DtF	-											
DTF	**0.722**											
DFR	**0.641**	**0.808**										
FFS	**0.857**	**0.827**	**0.708**									
FL	0.215	0.553	**0.404**	**-0.428**								
FW	**0.423**	**0.371**	**0.329**	**-0.404**	**0.397**							
GA	0.024	0.034	0.254	-0.07	-0.234	-0.063						
LC	0.195	**0.286**	0.183	-0.159	0.159	0.02	-0.079					
IC50	**0.315**	**0.504**	**0.42**	**0.409**	**-0.551**	**-0.391**	-0.036	-0.207				
FC	**0.446**	**0.337**	0.198	**-0.348**	0.161	**0.467**	-0.109	0.204	-0.023			
NOF	0.091	**0.390**	**0.321**	0.216	**-0.466**	-0.162	-0.055	0.231	0.134	-0.125		
YTH	0.154	**0.298**	0.163	**-0.287**	**0.785**	**0.464**	**-0.504**	0.119	**-0.529**	0.153	-0.069	-

Values in bold are different from 0 at the 0.05 level of significance level. DtF = days to 50 % flowering, DTF = days to 50% fruiting, DFR = days to first fruit ripe, FFS= days to first fruit set, FL = fruit length, FW= fruit width, GA = gallic acid content, LC = lycopene content, IC_{50} value, FC = total flavonoid content, NOF = number of fruits, YTH = yield (ton/ha)

4.8.3 Estimation of Correlation Coefficients among Pepper Genotypes (Combined)

The results for estimates of correlation coefficients among twelve traits of the pepper genotypes (combined) are presented in Table 28. Days to 50% fruiting showed highly significant and positive association with days to 50% flowering (0.732). Positive and highly significant correlation was observed between days to first fruit ripe, days to 50% fruiting (0.731) and days to 50% flowering (0.705). Days to first fruit set showed highly significance and positive correlation with days to 50 % flowering (0.770), days to 5% fruiting (0.797), and days to first fruit ripe (0.705). There was significant and positive correlation with fruit length and days to 50% fruiting (0.414) but negatively correlated with days to first fruit set (-0.291). Fruit width showed significant and positive correlation with fruit length (0.408) and days to 50% flowering (0.261). Significant and positive correlation was observed for gallic acid content and days to first fruit ripe (0.277) but negatively correlated with fruit length (-0.262). There was significant and positive correlation with lycopene content and fruit length (0.302) but negatively associated with (-0.240) gallic acid content. Antioxidant activity (IC_{50} value) showed significant and positive association with days to 50% flowering (0.201), days to 50% fruiting (0.277), days to first fruit set (0.204), but negatively associated with fruit length (-0.539), fruit width (-0.337), and lycopene content (-0.232). Total flavonoid content was significant and positively correlated with days to 50% flowering (0.214) and fruit width (0.263). there was significant and positive correlation with number of fruits per plant and days to 50% fruiting (0.336), days to first fruit ripe (0.279), total flavonoid content (0.291), days to first fruit set (0.252) but negatively associated with fruit length (-0.377). Yield (tons/ha) was highly significant and positively associated with fruit length (0.756). Yield (tons/ha) also showed highly significant and positive correlation with fruit width (0.562), significant and

positive for lycopene content (0.318) but negatively correlated with antioxidant activity (-0.478) and gallic acid content.

Table 28: Estimates of Correlation Coefficients of Twelve Traits in Pepper Genotypes under Field Conditions

Variables	DtF	DTF	DFR	FFS	FL	FW	GA	LC	IC50	FC	NOF	YTH
DtF	-											
DTF	**0.732**											
DFR	**0.583**	**0.731**										
FFS	**0.77**	**0.797**	**0.705**									
FL	0.191	**0.414**	0.149	**-0.291**								
FW	**0.261**	0.172	0.03	-0.192	**0.408**							
GA	0.014	0.056	**0.277**	-0.145	**-0.262**	-0.192						
LC	0.158	0.159	0.023	-0.041	**0.302**	0.183	**-0.240**					
IC50	**0.201**	**0.277**	0.186	**0.204**	**-0.539**	**-0.337**	0.078	**-0.232**				
FC	**0.214**	0.015	0.059	-0.072	-0.134	**0.263**	-0.027	0.186	0.134			
NOF	0.142	**0.336**	**0.279**	**0.252**	**-0.377**	0.094	0.057	0.086	0.048	**0.291**		
YTH	0.056	0.114	0.129	-0.075	**0.756**	**0.562**	**-0.453**	**0.318**	**-0.478**	0.038	0.065	-

Values in bold are different from 0 at the 0.05 level of significance. DtF = days to 50 % flowering, DTF = days to 50% fruiting, DFR = days to first fruit ripe, FFS= days to first fruit set, FL = fruit length, FW= fruit width, GA = gallic acid content, LC = lycopene content, IC_{50} value, FC = total flavonoid content, NOF = number of fruits, YTH = yield (ton/ha)

CHAPTER FIVE

5.0 DISCUSSION

5.1 VEGETATIVE TRAITS

5.1.1 Mean Plant Height of Pepper Genotypes

Plant height under field conditions ranged from 34.57 cm to 65.63 cm. This is in agreement with the findings of Nkansah *et al*. (2011) who observed a range from 32.1 cm to 68 cm. Mean plant height also ranged from 64.40 cm to 163.30 cm under greenhouse condition. The range however differed from the findings of Gomez-Guillamon and Cuartero, (1987). A wider range for plant height obtained under greenhouse conditions might be due to shade effect in the greenhouse. In general, plants in greenhouses grow taller than in the field. Taller *capsicum* species go with high cost of production from staking and makes harvesting difficult. Breeding for shorter and less support-dependent varieties is economical (Gomez-Guillamon and Cuartero, 1987) since lower height could influence a plant's ability to resist lodging (Nkansah *et al*., 2011). The genotype 9B which was the shortest under greenhouse as well as combined environment could be ideal for production under greenhouse condition because of its height advantage. It could also serve as a parent for breeding varieties resistant to lodging.

5.1.2 Mean Canopy Width

Among the genotypes, the mean canopy width ranged from 20.03 cm to 64.33 cm. This finding is not in agreement with the findings of Nkansah *et al.* (2011) who observed a range of 41.71 cm to 59.82 cm. Under greenhouse conditions, the genotypes had a wider range of canopy width than in the field. This could be attributed to the controlled climate in the greenhouse. Fitter and Hay (2002), stated that the maximum growth rate in plants is obtained when its environment is

manipulated to remove all constraints in growth. This implies that when optimum environmental influences required by plants are provided, the genetic influence is highly facilitated.

5.1.3 Mean Number of Leaves per Plant

The highest number of leaves produced in the genotypes under greenhouse conditions occurred in Galaxy and it was higher than the number produced under field conditions. On the other hand, Galaxy recorded the lowest number of leaves under field conditions indicating high genotype x environment interaction in Galaxy. Energy and resources needed for structural build-up in plants are obtained through photosynthesis. The main organ responsible for this process is the leaf (Lenis *et al*., 2006). According to Lahai *et al.*, (2013), leaves number per plant corresponds to the quantum of photosynthate produced and subsequently the yield. Thus, the higher number of leaves recorded among genotypes under greenhouse conditions than the field could be the reason for higher yields under greenhouse conditions.

5.1.4 Mean Stem Girth

Under field conditions, the range for stem girth of genotypes (0.45 cm to 1.1 cm) agrees with the findings of Berhanu *et al*., (2011) who reported a range from 0.72 cm to 1.24 cm. A range of 0.73 cm - 2.88 cm was recorded in the genotypes under greenhouse conditions. This was not consistent with the range reported by Perez-Grajeles *et al.* (2004) and Nsabiyera *et al*. (2013). The higher range under greenhouse conditions could be attributed to environmental influence.

5.2 Mean Chlorophyll Content

5.2.1 Mean Chlorophyll Content at Flowering Stage

The range of values for chlorophyll content in genotypes under field conditions ranged from 40.8 nm to 127.6 nm. This was higher than the findings of Ibrahim and Jaafar (2011) under field conditions. The values recorded under greenhouse conditions also ranged from 18.2 nm to 47 nm

in this study. Again, the findings of Ibrahim and Jaafar (2011) under greenhouse conditions were lower than in the current study. The higher range of chlorophyll content recorded under field conditions than in the greenhouse in this study could be attributed to their exposure to more solar energy than those under greenhouse conditions. According to Karpinski *et al*. (1997) most plants under open field conditions receive more solar energy than the greenhouse.

5.2.2 Mean Chlorophyll Content at Harvest

Chlorophyll content ranged from 26.7 nm to 116.3 nm under field conditions. The findings under field conditions were not in agreement with the findings of Kopsell *et al.* (2005). Under greenhouse conditions, chlorophyll content ranged from 21.7 nm to 96.1 nm. The range reported by Abu-Zahra (2012) was within the findings under greenhouse conditions reported in this study. The difference in the chlorophyll content under field and greenhouse environments might be due to the variation in the microclimate (Ibrahim and Jaafar, 2011).

5.3 REPRODUCTIVE TRAITS

5.3.1 Mean Days to 50% Flowering

The number of days to 50% flowering ranged from 28 days to 73 days among genotypes under field conditions. This was similar to the range reported by Pandit and Adhikary (2014). Under greenhouse condition, the days to 50% flowering ranged from 28 days to 97 days. The earliest genotype to flower (GR 202) recorded the same number of days to 50 % flowering under both environments. This could be attributed to a greater genetic influence than the environment. It has been reported in many crops that duration to flowering is strongly influenced genetically (Rahman and Bahl, 1986; Thurling and Ratinam, 1989). The genotypes GR 202, Vulcano, and Delhi Hot recording the earliest mean days to 50% flowering could be considered in breeding for earliness.

5.3.2 Mean Days to First Fruit Set in Pepper Genotypes

Days to first fruit set ranged from 28 days to 62 days under field conditions. This was consistent with the findings of Osei (2013). The results followed the same trend as in 50% flowering except in the result under field conditions where Local Hot Chili was the last to flower instead of Legon 18. Hence, it might be possible to predict earliness to 50% fruit set from earliness in first flowering.

5.3.3 Mean Days to 50% Fruiting in Pepper Genotypes

The lowest and highest number of days to 50% fruiting in the field was from 48 days to 90 days recorded in GR 202 and Legon 18 respectively while under greenhouse condition Vulcano (46 days) was the earliest and 9H (117 days) the latest. This indicates high genotype x environment interaction for earliness in fruiting. The similarity between earliness to 50% flowering and 50% fruiting exhibited by GR 202 would suggest that the same gene or gene complexes control earliness to flowering and earliness to fruiting. It has been reported that time of flowering influences fruit set and yield (Ishiyaku *et al*., 2005; Ferrara *et al*., 2011). The genotypes GR 202, Vulcano and Z-607 were the earliest to attain days to 50% fruiting. These genotypes therefore, could be selected for improvement in *Capsicum* species for early fruiting or may be directly used for production since getting rid of undesirable genotypes through selection is an essential tool in breeding for improvement in plant attributes (Idahosa *et al*., 2010).

5.3.4 Mean Days to First Fruit Ripening in Pepper Genotypes

Number of days to first fruit ripening under field conditions (56 days to 87 days) was not in agreement with the report of Hasanuzzaman *et al*. (2012). The number of days to first fruit ripening under greenhouse conditions (57 days to 108 days) was longer than under field conditions. This may be attributed to differences in environmental conditions including temperature and insolation.

5.4 FRUIT QUALITY TRAITS

5.4.1 Mean Fruit Length of Pepper Genotypes

Fruit length among genotypes ranged from 2.4 cm to 10.4 cm under field conditions. This covers the range reported by Hasanuzzaman *et al*. (2012) but is not consistent with the report of Berhanu *et al*. (2011). Under greenhouse conditions, the genotypes recorded fruit length range from 2.4 cm to 17.1 cm. The variability for this trait among genotypes could be attributed to genetic differences among them as well as genotype x environment interaction. Weiss (1971) reported that fruit length in *Capsicum* species is genetically controlled by polygenes. Genotypes ICPN16#7, GR 202 and 7A had the longest mean fruit length from the combined data. These genotypes could be selected for production to meet the needs of consumers who prefer large and long fruits.

5.4.2 Mean Fruit Width of Pepper Genotypes

Under field conditions, fruit width recorded in genotypes ranged from 0.55 cm to 1.46 cm. The ranges reported by Nkansah *et al*. (2011) and Nsabiyera *et al.,* (2013) were consistent with this findings. However, fruit width reported by Fonseca *et al*. (2008) was not consistent with these findings. Fruit width of genotypes under greenhouse conditions ranged from 0.62 cm to 2.24 cm. The genotype ICPN16#7 had the largest fruit width under both field and greenhouse conditions. This might be due to high genetic influence. The genotype ICPN16#7 could therefore be recommended for breeding and production purposes where large fruits are desired. However, the relatively higher performance under greenhouse conditions than the field suggests a better environmental conditions under the greenhouse than the field which implies the importance of genotype x environment interaction.

5.4.3 Mean Fruit Wall Thickness of Pepper Genotypes

The fruit wall thickness recorded in the genotypes had a range of 0.03 mm to 0.65 mm under field conditions. The range reported by Berhanu *et al.* (2011) was in agreement with the results obtained but the report of Seleshi (2011) varies from the results of this study. Under the greenhouse condition, fruit wall thickness ranged from 0.05 mm to 0.31 mm. From the combined data, the thickest fruit walls were recorded in the genotypes; ICPN16#7, 9F and Vulcano. These genotypes with thick fruit walls could have higher dry matter, a quality preference for dry pepper / processed pepper. Thus, they could be considered for selection towards production if the thick fruit wall can be translated to higher yield in powdered or pureed pepper.

5.4.4 Mean Number of Seeds per Fruit of Pepper Genotypes

The number of seeds per fruit recorded in the genotypes varied from 26 to 69 under field conditions. The results are not consistent with the range reported by Nkansah *et al*. (2011). A range of 20 to 100 seeds per fruits was recorded in genotypes under greenhouse conditions. The highest seeds per fruit recorded in genotype ICPN16#7 under both environments might be from genetic influence. The highest number of seeds recorded in ICPN16#7 may reflect a higher pungency since capsaicin which accounts for this occurs at the placenta where the seeds attach to the fruit. Again, higher number of seeds recorded in almost all genotypes under greenhouse conditions than the field might be due to the larger width of fruit recorded in genotypes in the greenhouse than the field and better pollination and fertility under greenhouse conditions.

5.5 YIELD QUALITY TRAITS

5.5.1 Mean Number of Fruits per Plant in Pepper Genotypes

Number of fruits per plant recorded in the genotypes under field conditions varied from 29 to 180 fruits per plant. This exceeded the range reported by Seleshi (2011). Under greenhouse conditions,

36 to 152 fruits per plant was recorded as the range. This was not consistent with the range reported by Nsabiyera *et al*. (2013). The variation and inconsistency in genotypes which recorded the highest and lowest number of fruits per plant in the two environments could be an indication of environmental influence.

5.5.2 Mean Yield (ton/ha) in Pepper Genotypes

Under field conditions, yield (ton/ha) recorded in genotypes ranged between 0.9 ton/ha and 5.4 ton/ha. The range reported by Seleshi (2011) is consistent with the results of the current study. Yield obtained under greenhouse conditions ranged from 1.5 ton/ha to 23 ton/ha. The results obtained by Perez-Grajales *et al*. (2004) was consistent with the current results. The genotype ICPN16#7 had the highest yield (ton/ha) under the two environments. The highest performance of ICPN16#7 in both environments for this trait makes it a favorite for consideration for selection towards breeding and production. The study showed a higher variation in yield between the greenhouse and the field. This suggests a better production under greenhouse conditions than in the field for the pepper species. The combined data showed the genotypes ICPN16#7, Galaxy and 7A recorded the highest yield (ton/ha). These genotypes could be selected for production and breeding purposes.

5.6. MEAN ANTIOXIDANT PROPERTIES OF PEPPER GENOTYPES

5.6.1 Mean Content of Phenolic Compounds in Genotypes

Contents of three phenolic acids viz gallic, vanillic and rosmaniric acids were determined in genotypes under field and greenhouse conditions. Vanillic acid content ranged from 8.3 mg/100 ml to 28.8 mg/100 ml under field conditions. This range was consistent with the report by Podesta (2009). Under greenhouse conditions, it ranged from 10.7 mg/100 ml to 18.8 mg/100 ml indicating lower vanillic acid production. This could be attributed to differences in the environmental

conditions, probably light and temperature. The rosmarinic acid content ranged from 6.5 mg/100 ml to 22 mg/100 ml under field conditions. The range of 13 mg/g to 47.3 mg/g reported by Bandoniene *et al*. (2005) was not consistent with the current study. This could be due to both genetic differences in the genotypes studied and environmental effects.

To summarize the performance of the phenolic acids, genotypes 9F and Pari Mild (PM) recorded the highest and the lowest contents respectively under field conditions in all the three phenolic acids. Genotype Pari Mild recorded the highest contents while both ICPN16#7 and Galaxy recorded the and lowest contents under greenhouse conditions. This might be an indication of an inherent genetic component that highly controls this trait in the genotypes. The level of the different phenolic acids differed with genotypes across environments. This might be due to genotype x environment interaction at each particular environment. It has been reported that the quantum of phenols and flavonoids that could be obtained from fruits is dependent on factors such as conditions during growth, extent of fruit ripening and storage (Zhang and Hamauzu, 2003; Marinova *et al.,* 2005; Navarro *et al*., 2006). The consistency of high performance of the genotypes Pari Mild, 9B, 9F, Local Hot Chili and Mayford across environments for these acids suggests that the genotypes could be selected for production or as a parent in a breeding programme which targets improved fruit quality in pepper.

5.6.2 Mean Lycopene Content of Pepper Genotypes

Lycopene content of genotypes under field conditions ranged from 0.03 mg/100 ml to 0.15 mg/100 ml. This was higher than the range reported by Chavez-Mendoza *et al.* (2013). Under greenhouse conditions, the content ranged from 0.05 mg/100 ml to 0.4 mg/100 ml. Lycopene content for the different genotypes varied across environments. This could be an indication of environmental effect on genotypes' performance in both environments. Genotypes 9F, Vulcano and Mayford

recorded the highest lycopene content. These genotypes could be selected for production for this trait.

5.6.3 Mean β Carotene Content of Pepper Genotypes

β Carotene content ranged from 0.14 mg/100 ml to 0.55 mg/100 ml under field conditions. The values (from 0.0039 mg/g to 0.0074 mg/g) reported by Chavez-Mendoza *et al.* (2013) was lower than the results from this experiment. The genotypes Delhi Hot, Vulcano and Pari Mild recorded the highest β Carotene contents and could be selected for production for this medicinal property.

5.6.4 Mean Total Flavonoid Content of Pepper Genotypes

Under field conditions, total flavonoid content ranged between 0.22 mg/100 ml and 0.79 mg/100 ml. The range of 0.306 µmolQ/g to 0.55 µmolQ/g reported by Rohanizah and Ishak (2012) was not consistent with the range recorded in the current study. This indicates higher variability in the genotypes investigated in the present study which would allow for selection for higher levels of flavonoids. Genotypes Vulcano, Pari Mild and 9A recorded the highest lycopene contents. These genotypes could thus be selected for this antioxidant property.

5.6.5 Mean Antioxidant Activity of Pepper Genotypes

Under field conditions, the antioxidant activity of genotypes ranged between 0.92 mg/ml and 1.96 mg/ml. The range of 0.795 µmolBHA/g to 1.893 µmolBHA/g recorded by Rohanizah and Ishak (2012) was not consistent with the range observed under field conditions. The genotypes under greenhouse conditions also recorded a range between 0.64 mg/ml and 1.65 mg/ml. The genotype 7A recorded the highest value for antioxidant activity under both greenhouse and field conditions which could be due to high genetic component for this trait in the genotype. Yahia *et al*. (2001) reported that a property of antioxidant activity of samples might be influenced by phenolic compounds. The antioxidant activity recorded by 7A under the greenhouse conditions was higher

than under the field conditions and might be due to environmental differences. The genotypes 7A, Z-607 and 7E were the genotypes with the highest antioxidant activity. Among these, 7A was consistently better across environments. It could be therefore selected for this trait.

5.7 BROAD SENSE HERITABILITY AND VARIANCE COMPONENTS OF TRAITS

5.7.1 Heritability and Variance Components for Agro-Morphological Traits of Pepper Genotypes under Field Conditions

For the agro-morphological traits, broad sense heritability ranged between 21.49 % and 95.26 %. Fruit wall thickness, fruit length and number of seeds per fruit recorded the highest heritability. The phenotypic characteristics of these traits were more influenced genetically than by environment. It would therefore be desirable to consider them among the genotypes for selection towards breeding and production ((Marame *et al*., 2009). Generally, many traits recorded values above 50% except yield, number of fruits per plant, plant height, stem girth and canopy width. In general, PCV was higher than GCV across all traits. GCV was close to PCV for the traits days to 50% fruiting, fruit length, fruit wall thickness, number of seeds per fruits and chlorophyll content at flowering stage. This indicates higher genetic influence over the traits than the environment. The other traits showed wider gaps between PCV and GCV indicating higher environmental influence on them which agrees with the findings of Berhanu *et al*., 2011. Higher genetic advance as a percentage of mean were also recorded in number of fruits per plant, number of seeds per fruits, and fruit length. These results indicate the possibility of higher responses to selection in these traits. Johnson *et al.* (1955) stated that using both heritability and genetic advance for selection is more efficient than the use of heritability alone as the only parameter.

5.7.2 Heritability and Variance Components for Agro-Morphological Traits of Pepper Genotypes under Greenhouse Conditions

Broad sense heritability for agro-morphological traits under greenhouse conditions ranged from 23.17 % to 96.94 %. However, stem girth recorded negative value for heritability. The best three heritability values for agro-morphological traits recorded under greenhouse condition were number of seeds per fruit, fruit length and 50% flowering. The other traits had values above 70 % except fruit width, fruit wall thickness, stem girth and number of fruits per plant. The high heritability recorded among most of the traits could be assumed to indicate that they were under more genetic influence for determination of the phenotype than under the environment. According to Chopra (2000), heritability gives an idea of the degree to which a trait could be influenced genetically. PCV across all the traits was higher than GCV. The closeness of GCV to PCV was recorded in the traits days to 50% fruiting, days to 50% flowering , fruit length , number of seeds per fruit, plant height, number of leave and canopy width . The closeness of GCV to PCV in these traits except canopy width were similar to the findings of Kaushik *et al*. (2011). The closeness of GCV to PCV shows higher genetic influence over these traits than the environment. Higher genetic advance were recorded on the traits number of seeds, days to 50% flowering and fruit length indicating a high potential for selection.

5.7.3 Heritability and Variance Components for Agro-Morphological Traits of Pepper Genotypes (combined)

Broad sense heritability was determined for agro-morphological traits by using the combined data. It ranged from 1.20 % to 87.20 %. The traits below, in a descending order showed a higher performance in heritability than the others; number of days to fruiting, days to 50% fruiting and Chlorophyll content at harvest. These results which differ from the individual (both greenhouse

and field conditions) heritability results are indication of genotype x environment interaction. In general, PCV was higher than GCV across the environments among all the traits. This is an indication of higher environmental influence on the traits. However, for the traits, number of days to first fruit ripening and number of days to 50% fruiting, GVC was close to PCV which could be attributed to a very high genetic component. The range for genetic advance by percentage mean was not in agreement with the findings of Idahosa *et al*. (2010). Generally, there were low values for genetic advance among the traits except days to 50% fruiting, fruit length, number of seeds per plant, number of fruits per plant and chlorophyll content at harvest which had values above 50%. This indicates a low potential for selection among genotypes.

5.7.4 Heritability and Variance Components for Phytochemicals and Antioxidant Activities of Pepper Genotypes under Field Conditions

Broad sense heritability under field conditions ranged from 65.34 % to 100 %. All the polyphenolic compounds had heritability values greater than 80% except β carotene. This was similar to the findings of Hedau *et al*. (2008). The high performance among genotypes for all these traits could be attributed to low environmental influence on the expression of the traits. This is an indication of a possible high genetic factor which controls the traits and this could be considered for pepper improvement programs. Ferrari and Torres (2003) stated that development of varieties with high antioxidant properties could assist in the improvement of man's health. PCV was higher in all antioxidants than GCV except for antioxidant activity (IC_{50} value) where both recorded 24.43 %. GCV which was the same as PVC in antioxidant activity (IC_{50} value) might be due to the higher genetic than environmental influence on the trait. GCV was close to PCV for vanillic acid and antioxidant activity indicating a high genetic effect in the expression of these traits. The genetic

advance by percentage mean indicated low phenotypic variances among the traits. This means that potential for selection among the traits would be very low.

5.7.5 Heritability and Variance Components for Phytochemicals and Antioxidant Activities of Pepper Genotypes under Greenhouse Conditions

Under greenhouse conditions, the heritability values for all the antioxidants except lycopene and carotene were greater than 70%. The low heritability for the two antioxidants might probably be attributed to environmental effect. The genotypes recorded 100 % heritability for antioxidant activity. This might be an indication of a very high genetic effect in the expression of this trait. PCV was higher than GCV in all the antioxidants. However, antioxidant activity recorded the same values for GCV and PCV which again suggests the possibility of a very high genetic influence on the trait. The antioxidant activity for the polyphenolic compounds gallic, vanillic and rosmarinic acids showed closeness of GCV to PCV. These could be attributed to a strong genetic influence on their performances. However, the other polyphenolic compounds showed wider gaps among themselves which might be due to environmental effect. Genetic advance by percentage mean recorded values above 50% for all the polyphenolic compounds except lycopene. The high heritability and genetic advance recorded could be used as combined parameters for selection of genotype for these traits.

5.7.6 Heritability and Variance Components for Phytochemicals and Antioxidant Activities of Pepper Genotypes (combined)

Vanillic, gallic and rosmarinic acids showed non-significant values for heritability. This agrees with the findings of Gusmini and Wehner (2007). This occurred because of the negative values obtained for the genetic variances other than error variances for these traits (Kiran *et al*., 2003). Again, the environmental variances for the polyphenolic compounds (except flavonoid content)

which were higher than the genetic variances could be attributed to high environmental (notably temperature and humidity) effects in both environments. The heritability values recorded for β carotene and total flavonoid were also low. However, heritability for antioxidant activity was high. GCV and PCV were wider apart showing again the effect of variation from both environment on the traits. Genetic advance by percentage mean was also non-significant in all traits except antioxidant activity and β carotene.

5.8 Estimation of Correlation among Pepper Genotypes under Field and Greenhouse Conditions, and across environments

From the results of the study carried out under greenhouse, field and across environments, fruit yield showed a positive and significant association with days to 50 % fruiting, days to fruit ripening, fruit length, number of fruits and fruit width. To maximize fruit yield, indirect selection of any of these yield contributing characters could be effective. The present finding was in agreement with the report by Vinod *et al*. (2013) who observed a positive and significant correlation of fruit yield with number of fruits in tomato. Similarly, a positive and significant association between fruit yield and fruit length was reported in a study by Kaushik *et al*. (2011) in tomatoes. Also, Fruit yield correlated negatively with days to first fruit set, gallic acid content and antioxidant activity. Thus, indirect selection for these traits to maximize yield would not be effective.

The positive and significant association of days to 50 % flowering with days to 50 % fruiting, days to fruit ripening, days to first fruit set, fruit width, IC_{50}, fruit length and flavonoid content indicated that genotypes which are late in fruiting have larger fruit width, high antioxidant activity, longer fruits and higher amount of flavonoid composition. This means that indirect selection for the trait to improve upon fruit width, antioxidant activity, fruit length and flavonoid content could

effectively be carried out. The present study agrees with the findings of Sandar and Teerayoot (2013) which showed significant and positive correlation in days to 50% flowering to days to pod formation in soybean.

Positive and significant associations of days to 50 % fruiting with the traits days to fruit ripening, days to first fruit set, fruit length, fruit width, lycopene content, IC_{50} value, flavonoid content and number of fruits were observed. This implies that pepper genotypes which are late in attaining 50 % fruiting are not only late in fruit ripening and attaining first fruit set, but are also characterized by having longer fruits length, high fruit width, higher amount of lycopene and flavonoid contents, high antioxidant activity as well as high number of fruits per plant. For crop improvement purposes selection for the trait, days to 50 % fruiting, will maximize fruit length, fruit width, lycopene content, antioxidant activity, flavonoid content and number of fruits.

The correlation of days to fruit ripe with days to first fruit set, fruit length, fruit width, IC_{50} and number of fruit per plant was significant and positive which implies that accessions which are late in fruit ripening have longer fruit length, high fruit width, high antioxidant activity and a higher number of fruits per plant. To improve upon fruit length, fruit width, antioxidant activity and number of fruits per plant, selection for the trait days to fruit ripening could be effective. A study by Cankaya *et al*. (2010) revealed a negative significant association between fruit maturity and number of fruits per plant. The positive and significant association of fruit width with number of fruits, fruit yield and flavonoid content suggested that accessions whose fruit recorded higher values of width also produced larger number of fruits, high fruit yield and high flavonoid content. Thus, indirect selection of one trait could be effective to improve upon the other.

The positive and significant correlation between lycopene content and flavonoid composition observed under field conditions implies that genotypes which contain higher amount of lycopene

also contain higher amount of flavonoid composition. The significantly negative association of days to first fruit set with fruit length, fruit width, antioxidant activity and number of fruits indicated that genotypes which are early in attaining 50 % fruiting produce fruits which are longer with larger fruit widths, high in antioxidant activity as well as high number of fruits. In order to improve upon fruit antioxidant activity, fruit length, width and number per plant, indirect selection for first fruit set could be effective. Under the greenhouse condition, gallic acid content correlated negatively with fruit yield per plant indicating that indirect selection of either one of the traits to improve upon the other would not be possible. Similarly, fruit length correlated negatively and significantly with IC_{50} value, flavonoid content and number of fruits per plant which suggested that genotypes with longer fruit length are high in antioxidant activity, contain higher amount of flavonoid composition as well as higher number of fruits per plant. The correlation between fruit length and number of fruits was statistically not significant in a study by Cankaya *et al*. (2010). A significant negative association between gallic acid and lycopene contents under field conditions revealed that accessions that contain higher amount of gallic acid have a minimal amount of lycopene. Indirect selection of any one of the traits to improve upon the other could not be effective.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The main objective for any crop improvement program is to identify potential traits among genotypes of a species and assess the extent to which these traits are heritable. Following this, the two key decision that could be made are to use the information gathered on the traits for inter or intra species enhancement of crops or recommend for production.

The current study revealed a large variation among the seventeen (17) hot pepper genotypes studied which gives an indication of a possible genetic variability among genotypes.

- There was high variation among genotypes for vegetative traits studied which included plant height, canopy width, number of leaves and chlorophyll content at flowering stage.
- Reproductive traits showed high variability among genotypes in days to 50% flowering, and days to 50% fruiting. The genotype GR 202 was the highest performer in the days to 50% flowering and days to first fruit set while Z-607 and Vulcano were the best in days to first fruit ripe and 50% fruiting respectively. The genotypes GR 202, Vulcano, and Z- 607 could be selected for improvement and production.
- There was high variation among genotypes for all the fruit quality traits which is signal for genetic variability that could be used for improvement. The genotype ICPN16#7 was the highest performer for all the fruit quality traits except fruit wall thickness where the highest were recorded in 9B. Genotype ICPN16#7 could be considered for production as well as a parent in fruit quality improvement program.
- For yield components, there was high variability among genotypes for yield. The genotype ICPN16#7 was the best performer in yield. The genotypes ICPN16#7, Galaxy, and 7A

could be considered for selection toward production or breeding program. There was also high variability within genotypes for number of fruits per plant where the genotype 9A recorded the highest number of fruits per plant.

- There was high variability among genotypes for the phytochemicals lycopene, total flavonoid and phenolic acids. The genotype 9F performed best for vanillic acid, gallic acid, and lycopene content while the highest for gallic acid, total flavonoid and β carotene were Pari Mild and Delhi Hot respectively. Antioxidant activity showed no significance among genotypes. However, antioxidant activity was generally very high among genotypes with the highest value recorded in genotype 7A.
- Heritability and genetic advance were generally high for the agro-morphological traits studied which is an indication of potential for selection in these traits. However, heritability was generally high for antioxidant properties under both environments but genetic advance was low among genotypes under field condition and high under greenhouse condition.
- Correlation analysis showed days to 50 % fruiting and flowering significant and associated positively with most of the traits studied.

6.2 Recommendation

The large variation which existed among the seventeen (17) genotypes for the traits studied need to be confirmed.

- Multi-locational trials of the genotypes would be one of the appropriate means to achieve this.
- Again, molecular characterization could also be used as an effective tool to find out whether variations were really genetic or environmentally influenced.

- Since the performance of most of the genotypes were higher in the greenhouse than the field for most of the traits, it would be appropriate to recommend the high performing genotypes for greenhouse pepper production.
- A larger collection should be evaluated to identify genotypes that will excel under field conditions to satisfy field growers of pepper.
- The phytochemical capsaicin should be considered in a future study since it is also one of the important antioxidants in pepper.

REFERENCES

Abu-Zahra, T. R. (2012).Vegetative, Flowering and Yield of Sweet Pepper as Influenced by Agricultural Practices. *Middle-East Journal of Scientific Research* 11 (9): 1220-1225.

Acquaah, G., (2007). Principles of plant genetics and breeding. Blackwell publishing 350 Main Street, Malden, MA 02148-5020, USA 9600 Garsington Road, Oxford OX4 2DQ, UK 550 Swanston Street, Carlton, Victoria 3053, Australia.

Agyare, R.Y. (2013). Genetic diversity studies in pepper (*Capsicum spp*). http://hdl.handle.net/123456789/6488.

Ahmed, I. A., Mikail, M. A., Bin Ibrahim, M., Bin Hazali, N., Rasad, M. S. B. A., Ghani, R. A. (2015). Antioxidant activity and phenolic profile of various morphological parts of underutilised Baccaurea angulata fruit. *Food Chemistry*: 172, 778–787.

Aleemullah, M., Haigh, A.M., Holford, P. (2000). Anthesis, anther dehiscence, pistil receptivity and fruit development in the Longum Group of *Capsicum annuum*. *Australian Journal of Experimental Agriculture* 40: 755-762.

Allard, R.W. (1960). *Principles of Plant Breeding*, 1st ed. John Wiley & Sons, New York. 485 pp.

Almeida, C.M.C.V., Dias, L., Okabe, E., Medeiros, J.R.P. (2005). Variability in genetic resources of cacao in Rondonia, Brazil. *Crop Breeding and Applied Biotechnology* 5: 318-324.

Andrews, J. (1995). Peppers: The Domesticated Capsicums, New (ed.) University of Texas Press, Austin. 186 pp.

Arnel, R. H. (2011). Evolution of plant breeding. *Crop Breeding and Applied Biotechnology*, 11: 197-206.

Asian Development Bank (2014). Technologies to support climate change adaptation. Mandaluyong City, Philippines: Asian Development Bank.

Asimi, O. A., Sahu, N. P., Pal, A. K. (2013). Antioxidant capacity of crude water and ethylacetate extracts of some Indian species and their antimicrobial activity against Vibrio vulnificus and Micrococcus luteus. *Journal of Medicinal Plants Research*, 7(26), 1907–1915.

Aziagba, B.O., Okeke, C.U., Ezeabara, C.A., Ilodibia, C.V., Uka, C.J. (2015). Macro Morphological Observations in *Capsicum* Varieties Cultivated in Awka Anambre State South Eastern Nigeria. *Am. J. Life. Sci. Res*. Vol. 3, Issue 1: 30-34.

Bajracharya, J., Steele, K.A., Jarvis, D.I., Sthapit, B.R., Witcombe,J.R. (2006). Rice landrace diversity in Nepal: Variability of agro-morphological traits and SSR markers in landraces from a high altitude site. *Field Crops Res*., 95: 327-335.

Bandoniene, D., Murkovic, M.,Venskutonis, P. R. (2005). Determination of Rosmarinic Acid in Sage and Borage Leaves by High-Performance Liquid Chromatography with Different Detection Methods. *Journal of Chromatographic Science*, Vol. 43.

Baral, J.B., Bosland, P.W. (2004). Unraveling the species dilemma in *Capsicum frutescens* and *C. chinense* (Solanaceae): A multiple evidence approach using morphology, molecular analysis, and sexual compatibility. *Journal of the American Society for Horticultural Science* 129: 826-832.

Barros, L., Ferreira, M.J., Queiros, B., Ferreira, I., Baptista, P. (2007), Total phenols, ascorbic acid, beta carotene and lycopene in Portuguese wild edible mushrooms and their antioxidant activities. *Food Chemistry***,** 103 (2): 413-419.

Basu, A., Imrhan, V. (2006). Tomatoes versus lycopene in oxidative stress and carcinogenesis: Conclusions from clinical trials. *Eur. J. Clin. Nutr*. 2006, 1, 1–9.

Bendich, A. (1989). Carotenoids and the immune response. *J Nutr*, 119(1):112-5.

Berhanu, Y., Derbew, B., Wosene, G., Fedaku, M. (2011). Variability, Heritability and genetic advance in Hot Pepper (Capsicum annuum L.) Genotypes in West Shoa, Ethiopia. *American-Eurasian J. Agric. & Environ, Sci*., 10(4): 587-592, 2011.

Berke, T. G., Shieh, S. C.(2001).Handbook of herbs and spices; *Capsicum*, chillies, paprika, bird's eye chilli; Asian Vegetable Research and Development Center, Taiwan.

Berke, T.G. (2000). Hybrid Seed Production in *Capsicum*. In Hybrid Seed Production in Vegetables, Rationale and Methods in Selected Species, A.S. Basra (ed.). Food Products Press. 135: 49-67.

Bonsu, K.O., Owusu, E.O., Nkansah, G.O., Oppong-Konadu, E., Adu-Dapaah, H. (2003). Morphological characterisation of hot pepper (*Capsicum* sp.) Germplasm in Ghana. *Ghana J. Hortic*., 2: 17-23.

Bosland, P.W. (1996). *Capsicums*: Innovative uses of an ancient crop. p. 479-487. In: J. Janick (ed.), *Progress in new crops*. ASHS Press, Arlington, VA.

Bosland, P.W., Votava, E.J. (2000). Peppers: Vegetable and Spice *Capsicums*. Crop Production Science in Horticulture 12. CAB International Publishing, Wallingford, England, UK. 204 pp.

Bouchelta, A., Blenzar, A., Beavougui, A. J. P. , Lakhlifi, T. (2003). Étude del'activité insecticide des extraits de *Capsicum frutescens* (Solanacées) sur *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). *Rev. Méd.Pharm. Afr*. 17:19–28.

Bouchelta, A., Boughdad, A., Blenzar, A. (2005). Effets biocides des alcaloïdes, des saponines et des flavonoïdes extraits de *Capsicum frutescens* L. (Solanaceae) sur *Bemisia tabaci* (Gennadius)

Bowman, J. C. (1972) .Genotype x environment interactions. *Ann. Genet. Sel. Anim*., 4(1): 117-123.

Brand-Williams, W., Cuvelier, M. E, Berset, C. (1995).Use of a Free Radical Method to Evaluate Antioxidant Activity. *Lebensm.-Wiss. u.-Technol*., 28.25-30.

Burton, G.W., Ingold, K.U. (1984). Beta-Carotene: an unusual type of lipid antioxidant. Science 1984; 224:569–573.

Cai, Y.Z., Luo, Q., Sun, M., Corke, H. (2004). Antioxidant activity and phenolic compounds of 112 traditional Chinese medicinal plants associated with anticancer. *Life Sci*., 74: 2157–2184.

Campos, M. R. S., Gomez, K. R., Ordonez, Y. M., Ancona, D. B. (2013). Polyphenols, Ascorbic Acid and Carotenoids Contents and Antioxidant Properties of Habanero Pepper (*Capsicum chinense*) Fruit. *Food and Nutrition Sciences*, 4: 47-54.

Cankaya, S., Balkaya, A., Karaagac, O. (2010). Canonical correlation analysis for the determination of relationships between plant characters and yield components in red pepper [*Capsicum annuum* L. *var*. *conoides* (Mill.) *Irish*] genotypes. *Spanish Journal of Agricultural Research*, 8(1): 67-73.

Caribbean Export Development Agency – CEDA (2009). "Hot Pepper Project Phase 1 Market Research on the viability and export potential of the Regional Hot Pepper industry."

Carlos, E.D.M., Telma, N.S.P., Karina, P.D. (2011). Reproductive characterization of interspecific hybrids among *Capsicum* species. Crop Breed. Appl. *Biotechnol. (Online) vol*.11 no.3.

Carmichael, J.K. (1991). Treatment of herpes zoster and postherpetic neuralgia. *Am. Family Physician* 44:203-210.

Ceballos-Muller, J., Toon, D. (2010). The Hot Pepper Agri-business Cluster in the Northern Region of Ghana; *ICRA Mission Report*.

Chaim, B. A., Borovsky, Y., Rao, G.U., Tanyolac, B. and Paran, I. (2003). *fs3.1*: A major fruit shape QTL conserved in *Capsicum*. *Genome* 46: 1-9.

Chavez-Mendoza, C., Sanchez, E., Carvajal-Millan, E., Munoz-Marquez, E., Guevara-Aguilar, A. (2013). Characterization of the Nutraceutical Quality and Antioxidant Activity in Bell Pepper in Response to Grafting. Molecules 18, 15689-15703.

Choi, K.S. 1985. Physiological and ecological studies on the germinability of pepper (*Capsicum annuum L*.) seeds at low temperature. *Research Report of RDA (Hort)* 27: 46-87.

Chopra, V. L. (2000). Plant breeding Theory and practice. 2nd ed. Oxford and IBH Pub. Co. Pvt. Ltd, New Delhi, p.10.

College of agriculture and Consumer Sciences (2010). University of Ghana, Legon. http://www.bme.ug.edu.gh/cacs/page15.html

Csilléry, G. (2006). Pepper taxonomy and the botanical description of the species. *Acta. Agron. Hung.* 54:151–66.

Csillery, G., Quagliotti, L., Rota, A. (1986). Natural cross-pollination experiment on pepper in Piedmont, Italy. *Capsicum Newslett.*, 5: 38-39.

Dagnoko, A. S., Niamoye, Y., Nadou, P.S., Olagorite, A., Aminata, D., Kadidiatou, G., Aissata, T., Seriba, K., Daoule, D., (2013). Overview of pepper (*Capsicum* spp.) breeding in West Africa. *African Journal of Agricultural Research*, Vol. 8(13), pp. 1108-1114, 11.

de Swart, E.A.M., Groenwold, R., Kanne, H.J., Stam, P., Marcelis, L.F.M., Voorrips. R.E. (2004). Non-destructive estimation of leaf area for different plant ages and accessions of *Capsicum annuum* L. *Journal of Horticultural Science and Biotechnology* 79: 764-77.

De, A. K. (2003). *Capsicum*: The Genus *Capsicum*. Medicinal and Aromatic Plants - Industrial Profiles Volume 33. Taylor & Francis, London and New York. pp: 275.

Debra, D. F. (2003). Botanical Briefs: *Capsicum* Peppers; Department of Dermatology, Indiana University, 550 N University Blvd, UH 3240, Indianapolis,IN 46202.

Deepa, N., Kaur, C., George, B., Singh, B., Kapoor, H.C. (2007). *LWT-Food Science and Technology*, 40:212-219.

Dell'Aquila, A., (2004). Cabbage, lentil, pepper and tomato seed germination monitored by an image analysis system. *Seed Science and Technology* 32: 225-229.

Dharamadhaj, P., Prakash, P. (1978). Development of the anther and ovule in *Capsicum* L. *Australian Journal of Botany* 26: 433-439.

Dias, G.B., Gomes, V.M., Moraes, T.M.S., Zottich, U.P., Rabelo, G.R., Carvalho, A.O., Moulin, M., Goncalves, L.S.A., Rodrigues, R., da Cunha, M. (2013). Characterization of *Capsicum* species using anatomical and molecular data. *Genetics and Molecular Research*, 4(2): 1-14.

El-Agbar, Z. A., Shakya, A. K., Khalaf, N. A., Al-Haroon, M. (2008). Comparative Antioxidant Activity of Some Edible Plants. Turk J Biol., 32:193-196.

Elizanilda, R. R., Mailson, M., R., Izadora, W. F. M., Lidiany A. B. (2011). Morphological and chemical characterization of fruits of *Capsicum* spp. Accessions. *Horticultura Brasileira* vol.29 no.3.

Falconer, D. S. (1960). Introduction to Quantitative Genetics. The Ronald Press Company, New York. Printed in Great Britain by Robert MacLehose and Company Limited, Glasgow.

FAO (1996b) Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources and the Leipzig Declaration, adopted by the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, 17–23 June 1996. Rome: Food and Agricultural Organization of the United Nations.

Farshadfar, E., Estehghari, M. R. (2014). Evaluation of phenotypic variability, genetic parameters, heritability and genetic gain in bread wheat genotypes under rainfed conditions. *International Journal of Biosciences*. Vol. 4, No. 12: p. 193-201.

Ferrara, A., Lovelli, S., Di Tommaso, T., Perniola, M. (2011). Flowering, growth and fruit setting in greenhouse bell pepper under water stress. *J. Agron.*, 10: 12-19.

Ferrari, C.K.B., Torres, E.A.F.S. (2003). Biochemical pharmacology of functional foods and prevention of chronic diseases of aging. *Biomed. Pharmacother. 57:251–260.*

Fitter, A. H., Hay, R. K. M. (2002). Environmental Plant Physiology (3rd ed.). Academic Press, A division of Harcourt inc. Harcourt Place, 32 Jamestown Road, London NWY 7BY, UK. http://www.academicpress.com

Fonseca, R. M., Lopes, R., Barros, W. S., Lopes, M. T. G., Ferreira, F. M. (2008). Morphologic characterization and genetic diversity of *Capsicum chinense Jacq*. accessions along the upper Rio Negro – Amazonas. *Crop Breeding and Applied Biotechnology* 8: 187-194.

Furiga, A., Lonvaud-Funel, A., Badet, C. (2009). In vitro study of antioxidant capacity and antibacterial activity on oral anaerobes of a grape seed extract. *Food Chem*., 113: 1037-1040.

Geissman, T.A., Hinreiner, E. (1952). Theories of the biogenesis of flavonoid compounds. *Botan. Rev., 18*:77-164.

Geleta, L., (1998). Genetic variability and association study for yield, quality and other traits of yield of hot pepper *(Capsicum species*).

GenStat Computer Statistical Software (2009). *https://www.vsni.co.uk/about-vsni/press-and-media/genstat-12th-edition.*

Gibbon, D., Pain, A. (1985). Crops of the Drier Region of the Tropics. Longman, London, New York, pp: 134-139.

Gniffe, P.A., Shieh, S.C., Lin, S.W., Sheu, Z.M, Chen, J.R., Ho, F.I., Tsai, W.S., Chou, Y.Y., Wang, J.F., Cho, M.C., Schafleitner, R., Kenyon, L., Ebert, A.W., Srinivasan, R., Kumar,

S. (2013). Pepper research and breeding at AVRDC-The World Vegetable Center. XV EUCARPIA Meeting on Genetics and Breeding of *Capsicum* and Eggplant.

Goldfarb, A. H. (1993). Antioxidants: role of supplementation prevent exercise-induced oxidative stress, Medicine and Science in Sports and Exercise, 25:232-236.

Gomez-Guillamon, M. L., (1982). Gdiecna de caracteres aplicables a la mejora del pimiento (*C. annuum L.*) en cultivo bajo invernadero. Tesis Doctoral. Universidad de Malaga (Espana), 358pp.

Gomez-Guillamon, M.L., Cuartero, J., (1987). Inheritance of vegetative characters in pepper (*Capsicum annuum L.*). *Agronomie, EDP Sciences*, 7 (4): pp.271-277.

Goncalves, L.S., Rodrigues, R, Amaral Jr., A.T., Karasawa, M. (2008). Comparison of multivariate statistical algorithms to cluster tomato heirloom accessions. *Genet. Mol. Res.* 7: 1289-1297.

Grubben, G.J.H., Mohamed, E.T.I (2004). *Capsicum annuum L*. In: Grubben, G.J.H. & Denton, O. A. (Editors). PROTA 2: Vegetables/Légumes. [CD-Rom]. PROTA, Wageningen, Netherlands.

Gusmini, G., Wehner, T. C. (2007). Heritability and Genetic Variance Estimates for Fruit Weight in Watermelon. *HortScience* 42(6):1332–1336.

Halliwell, B., Gutteridge, J. M. C. (1998). Free Radicals in Biology and Medicine, Oxford University Press, Oxford, UK, 1998.

Harborne, J. B. (1989), General procedures and measurement of total phenolics. *Methods in Plant Biochemistry*, 1: 1–28. London: Academic Press.

Hasanuzzaman, M., Hakim, M. A., Fersdous, J., Islam, M. M., Rahman, L. (2012).Combining ability and heritability analysis for yield and yield contributing characters in chilli (*Capsicum annuum*) landraces. *Plant Omics Journal* 5(4):337-344.

Haussmann, B.I.G., Parzies, H. K., Presterl, T., Susic, Z., Miedaner, T. (2004). Plant genetic resources in crop improvement. *Plant Genetic Resources* 2(1); 3–21.

Hedau, N. K., Saha,S., Singh, G., Gahlain, A., Mahajan, V., Gupta, H. S. (2008).Analysis of Genetic Variability for Nutritional Quality Traits in Hot Pepper (*Capsicum annuum* L.). *J. Plant Genet. Resour. 21(2): 85-89.*

Heneman, K., Ziden-bergCherr, S. (2008). Nutritional and Health Infor-Sheet for Health professionals. Department of Nutrition, University of California Davis, CA. 95616 – 8669.

Hernandez-Verdugo, S., Oyama, K., Vazquez-Yanes, C. (2001b). Differentiation in seed germination among populations of *Capsicum annuum* along a latitudinal gradient in Mexico. *Plant Ecology* 155: 245-257.

Hertog, M.G.L., Feskens, E.J.M, Hollman, P.C.H, Katan, M.B., Kromhout, D. (1994). Dietary flavonoids and cancer risk in the Zutphen Elderly Study. *Nutr. Cancer*, 22(2): 175-184.

Hill, T.A., Ashrafi, H., Reyes-Chin-Wo, S., Yao, J., Stoffel, K., Truco, M.A., Kozik, A., Michelmore, R.W., Deynze, A.V. (2013). Characterization of *Capsicum annuum* genetic diversity and population structure based on parallel polymorphism discovery with a 30K Uni-gene Pepper Gene Chip. *Plos One*, 8(2): 1-16.

Hot, J. (2010). The Domesticated *Capsicum* Species. www.chilefoundry.com

Ibrahim, M. H., Jaafar, H. Z. E. (2011). Photosynthetic capacity, photochemical efficiency and chlorophyll content of three varieties of *Labisia pumila Benth*. exposed to open field and greenhouse growing conditions. *Acta Physiol Plant* 33:2179–2185.

Idahosa, D. O., Alika, J. E., Omoregie, A. U. (2010). Genetic Variability, Heritability and Expected Genetic Advance as Indices for Yield and Yield Components Selection in Cowpea (*Vigna unguiculata (L.) Walp*. *Academia Arena* 2(5):22-26.

Ikpeme, E.C., Henry, P., Orim, O.A. (2014). Comparative Evaluation of the Nutritional, Phytochemical and Microbiological Quality of Three Pepper Varieties. *Journal of Food and Nutrition Sciences.* Vol. 2, No. 3, 2014, pp. 74-80.

IPGRI, AVRDC and CATIE (1995). Descriptors for *Capsicum* (*Capsicum spp*.). International Plant Genetic Resources Institute, Rome, Italy; the Asian Vegetable Research and Development Center, Taipei, Taiwan, and the Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica.

Ishiyaku, M. F., Singh, B. B., Craufurd, P. Q. (2005). Inheritance of time to flowering in Cowpea (*Vigna unguiculata* (L.) Walp.). *Euphytica*, 142: 291-300.

Jarret, R.L., Dang, P. (2004). Revisiting the waxy locus and the *Capsicum annuum* L. complex. *Georgia Journal of Science* 62: 117-133.

Jeffrey, H. M., (2005). Pepper seed production. *An organic seed production manual for seed growers in the Mid-Atlantic and South*.

Johnson, H. W., Robinson, H. F., Comstock, R. E. (1955). Estimates of genetic and environmental variability in soybeans. *Agronomy Journal* 47:314-318.

Karpinski, S., Reynolds, H., Karpinska, B. (1997). Photosynthesis electron transport regulates the expression of cytosolic ascorbate peroxidase genes in Arabidopsis during excess light stress. *Plant Cell* 9:627–640.

Kaushik, S.K., Tomar, D.S., Dixit, A.K. (2011) .Genetics of fruit yield and its contributing characters in tomato (*Solanum lycopersicom*). *Journal of Agricultural Biotechnology and Sustainable Development* Vol. 3(10): 209-213.

Khah, E.M., Passam, E.C. (1992). Flowering, fruit set and development of the fruit and seed of sweet pepper (*Capsicum annuum* L.) cultivated under conditions of high ambient temperature. *J. Hortic. Sci*., 67: 251-258.

Kiran, P. S., Bhatia, V. K., Rao, A. R (2003). Sampling Distributions of Heritability. *Jour. Ind. Soc. Ag. Statistics* 56(3): 294·301.

Knapp, S. (2002). Tobacco to tomatoes: A phylogenetic perspective on fruit diversity in *Solanaceae*. *Journal of Experimental Botany* 53: 2001-2022.

Knapp, S.L., Bohs, M., Nee, D., Spooner, M. (2004). *Solanaceae* – A model for linking genomics with biodiversity. *Comparative and Functional Genomics* 5: 285-291.

Koes, R., Verweij, W., Quattrocchio, F. (2005). "Flavonoids: a colorful model for the regulation and evolution of biochemical pathways," *Trends in Plant Sciences*, vol. 10, no. 5: 236–242.

Kopsell, D. A., Kopsell, D. E, Curran-Celentano, J. (2005). Carotenoid and Chlorophyll Pigments in Sweet Basil Grown in the Field and Greenhouse. *HortScience* Vol.40 (5): 1230 –1233.

Krinsky, N.I., Johnson, E. J. (2005). Molecular Aspects of Medicine; 26:459–516.

Kuljarachanan, T., Devahastin, S., Chiewchan, N. (2009). Evolution of antioxidant compounds in lime residues during drying. *Food Chem*., 113: 944-949.

Kumar, O.A., Panda, R.C., Rao, K.G. R. (1987). Cytogenetic studies of the F1 hybrids of *Capsicum annuum* with *C. chinense* and *C. baccatum*. *Theoretical and Applied Genetics* 74: 242-246.

Kwatei, Q. E., Nunekpeku, W., Owusu-Ansah, M., Sarkodie, A., A., Selorm, K. O. E., Amoatey, M. H. (2014). Agronomic Evaluation of Eight Genotypes of Hot Pepper (*Capsicum spp* L.) in a Coastal Savanna Zone of Ghana. *Journal of Biology, Agriculture and Healthcare: Vol. 4, No. 24*: 16 – 28.

Lahai, M.T, Ekanayake, I.K., Koroma, J. P. C. (2013). Influence of canopy structure on yield of cassava cultivars at various toposequences of an inland valley agro ecosystem. *Journal of Agricultural Biotechnology and Sustainable Development: Vol. 5(3), pp. 36-4.*

Laurentin, H., (2009). Data analysis for molecular characterization of plant genetic resources. Genet. Res. *Crop Evol*. 56: 277-292.

Lee, J. J., Crosby, K. M., Yoo, K. S., Lescobar, D. I. (2005). *Sci. Hortic.*, 106:341-352.

Lee, S. K., Kader, A. A. (2000). Pre-harvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol*. 20: 207-220.

Lenis, J. I, Calle, F., Jaramillo, G., Perez, J. C., Ceballos, H., Cock, J. H. (2006). Leaf retention and cassava productivity. *Field Crops Res.*, 95:126-134.

Liu, W.Y., Kim, B.D., Kang, B.C., Harn, C.H., Jahn, M. (2009). Peppers. *Compendium of Transgenic Crop Plants*. 6: 73-98.

Maheshwari, R. B., Chandrashekhar, G. P. (2011).Assessment of genetic diversity among *Capsicum annuum* L. genotypes using RAPD markers. *African Journal of Biotechnology* Vol. 10(76), pp. 17477-17483.

Marame, F., Dessalegne, L., Fininsa, C., Sigvald, R. (2009). Heterosis and heritability in crosses among Asian and Ethiopian parents of hot pepper genotypes. *Euphytica* 168:235-247.

Marinova, D., Ribarova, F., Atanassova, M. (2005). Total phenolics and total flavonoids in Bulgarian fruits and vegetables. *Journal of the University of Chemical Technology and Metallurgy*, 40:255-260.

Matos. H. R., Capelozzi, V. L., Gomes, O. F., Di Mascio, P. D., Mederios, M. H. G. (2001). Lycopene inhibits DNA damage and liver necrosis in rats treated with ferric nitrile triacetate. *Arch. Biochem. Biophys*. 396:171–177.

Mehmet, K. B., Dursun, E. (2011). Evaluation of Morphological and Agronomical Characterization of Turkish Pepper Accessions. *International Journal of Vegetable Science*, 17(2): 115-135.

MiDA (2010). A publication of Millennium Development Authority in conjunction with the United States Millennium Challenge Corporation.

Middleton, E. J. (1998). Effect of plant flavonoids on immune and inflammatory cell function. *Advances in Experimental Medicine and Biology*, vol. 439:175–182, 1998.

Miguel, A. C., Fernando, M., Ligia, B., Jairo, C., Ignacio, I., (2010). A Brief Morphological Description of a Small Internal Fruit Grown in Habanero Pepper (*Capsicum chinense Jacq*.) Main Fruit.

Mishra, A. S., Kumar, S., Pandey, A. K. (2013). "Scientific validation of the medicinal efficacy of Tinospora cordifolia." *The Scientific World Journal*, vol. 2013(2013), Article ID 292934.

Nadeem, M., Muhammad, F. A., Rafiq K. M., Sa- eed, M., Riaz, A. (2011). Antioxidant Potential of Bell Pepper (*Capsicum annum* L.) a Review," *Pakistan Journal of Food Science*, Vol. 21, No. 1-4:pp. 45-51.

Nagata, M., Yamashita, I. (1992): Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. *Journal of Japanese Society of Food Science and Technology*, 39, 925–928.

Navarro, J. M., Flores, P., Garrido, C., Martinez, V. (2006). Changes in the contents of antioxidant compounds in pepper fruits at different ripening stages, as affected by salinity. *Food Chemistry*, 96:66-73.

Ndour, D. (1998). Tests of Agro-morphological characterization and genetics of salt tolerance in rice (*Oryza sativa* L.) in the Senegal River Delta. Memory Master II, University Cheikh Anta Diop in Dakar: pp. 1-27.

Nechif, O., Filimon, R., Szilagyi, L. (2011). "Genetic variability, heritability and expected genetic advance as indices for yield and yield components selection in common bean (*Phaseolus vulgaris* L.)," *Scientific Papers, UASVM Bucharest, Series A.*

Nisha, R., Arulmozhi, K. (2013). Efficacy of heat treatment on the *in vitro* antioxidant activity of selected spices. *Int.J.Curr.Microbiol.App.Sci* (2013) 2(11): 13-18.

Nkansah, G. O., Ayarna, A., Gbokie, T. J. (2011). Morphological and Yield Evaluation of Some *Capsicum* Pepper Lines in Two Agro-Ecological Zones of Ghana. *Journal of Agronomy*, 10: 84-91.

Norman, J.C. (1992). *Tropical vegetable crops.* Arthus H. Stockwell Ltd. Devon pp 78-87.

Nostro, A., Germano, M. P., D'angelo, V., Marino, A., Cannatelli, M.A. (2000). Extraction methods and bioautography for evaluation of medicinal plant antimicrobial activity. *Lett Appl Microbiol* 30: 379-384.

Nsabiyera, V., Logose, M., Ochwo-Ssemakula, M., Sserewagi, P., Gibson, P., Ojiewo, C. (2013). Morphological Characterisation of Local and Exotic Hot Pepper (*Capsicim annuum* L.) Collection in Uganda. *Bioremediation, Biodiversity and Bioavailability*, 7 (1): 22-32.

Nwankiti, O. C. (1976). Cytogenetics of some Nigerian peppers – genus *Capsicum*. II. Hybrid origin of *C. frutescens*. *Nigerian Journal of Science* 10: 61-75.

Nyadanu, D., Aboagye, L. M., Akromah, R., Osei, M.K., Dordoe, M. B. (2014). Agro-morphological characterisation of *gboma* eggplant, an indigenous fruit and leafy vegetable in Ghana. *African Crop Science Journal*, Vol. 22, No. 4, pp. 281 – 289.

Nyquist, W. E. (1991). Estimation of heritability and prediction of Selection Response in Plant Populations. *Crit. Rev. Plant Sci*. 10: 235 – 322.

Ofosu-Budu, K. G. (2003)**.** Performance of citrus rootstocks in the forest zone of Ghana. *Ghana J. Hort.*, 3: 1-9.

Okubo, T., Yokoyama, Y., Kano, K., Cell, I. (2003). Death Induced by the Phenolic Antioxidant Tert-Butylhydroquinone and Its Metabolite Tert-Butylquinone in Human Monocytic Leukemia U937 Cells. *Food and Chemical Toxicology*, 41: 679-688.

Omoigui, L., Ishiyaku, M., Kamana, A., Alab, S., Mohammed, S. (2006). Genetic variability and heritability studies of some reproductive traits in cowpea (*Vigna ungiculata* (L.) *Walp*). *African Journal of Biotechnology* 5:1191-1195.

Onus, A.N., Pickersgill, B. (2004). Unilateral incompatibility in *Capsicum* (*Solanaceae*): Occurrence and taxonomic distribution. *Annals of Botany* 94: 289-295.

Oparaeke, A. M., Dike, M. C., Amatobi, C.I. (2005). Evaluation of botanical mixtures for insect pests management on cowpea plants. *Journal of Agriculture and Rural Development in the Tropics. Subtropics* 106(1):41–48.

Oroian, M., Escriche, I. (2015). Antioxidants: Characterization, natural sources, extraction and analysis. *Food Research International* 74 (2015) 10–36.

Osei, R. (2013). Effect of Age of Transplants, Spacing, Supplementary Application of Sulphate of Ammonia and Harvesting Intervals on Growth, Yield and Some Postharvest Qualities of Chilli Pepper (*C. annuum*) var. Legon 18.

Panda, R.C., Kumar, O. A., Rao, K.G. R. (2004). Cytogenetic studies of some F1 hybrids between wild and cultivated taxa of *Capsicum* L. *Cytologia* 69: 203-208.

Pandit, M. K., Adhikary, S. (2014). Variability and Heritability Estimates in Some Reproductive Characters and Yield in Chilli (*Capsicum annuum* L.). *International Journal of Plant & Soil Science, 3(7): 845-853.*

Paszkiewicz, M., Budzynska, A., Rozalska, B., Sadowska, B. (2012). The Immunomodulatory Role of Plant Polyphenols. Postepy Higieny Medycyny Doswiadczalnej, 66, 637-646.

Paul, W. B., Stephanie J. W. (2010). Measuring Chili Pepper Heat.

Perez-Grajales, M., Gonzalez-Hernandez, A. V., Mendoza-Castillo, M. C., Pena-Valdivia, C., Pena-Lomeli, A., Sahagun-Catellanos, J. (2004). Physiological Characterization of Manzano Hot Pepper (*Capsicum pubescens* R&P) Landraces. *J. Amer. Soc. Hort. Sci*. 129(1): 88-92. 2004.

Perucka, I., Meterska, M. (2001). Phenylalanine ammonia Lyase and antioxidant activities of lipophilic fraction of fresh pepper fruits Capsicum annum. *Int. J. Food Sci. and Technol.* 2:189-192.

Pickersgill, B. (1988). The genus *Capsicum*: A multidisciplinary approach to the taxonomy of cultivated and wild plants. *Biologisches Zentralblatt* 107: 381-389.

Pickersgill, B. (1991). Cytogenetics and evolution of *Capsicum* L. Pp. 139-160 *in* T. Tsuchiya and P.K. Gupta, Chromosome Engineering in Plants: Genetics, Breeding, Evolution, Part B. Elsevier, Amsterdam.

Pickersgill, B. (1997). Genetic resources and breeding of *Capsicum* spp. *Euphytica* 96: 129-133.

Podesta, R. (2009). Caracterização Físico-Química, Anatômica e Potencial Tecnológico de Frutos de Raleio da Ameixeira (*Prunus Salicina*) Cultivar Harry Pickstone

Pourmorad, F., Hosseinimehr, S. J., Shahabimajd, N. (2006). "Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants," *The African Journal of Biotechnology*, vol. 5, no. 11: 1142–1145.

Rahman, M. A., Bahl, P. N. (1986). Evaluation of early generation testing in chickpea. *Plant Breeding* 97: 82-87.

Rajib, R., Tah, J. (2011). Evaluation of Genetic Parameters for Agro-metrical Characters in Carnation Genotypes. *African Crop Science Journal*, Vol. 19, No. 3: 183 – 188.

Randle, W. M., Homna, S. (1980). Inheritance of low temperature emergence in *Capsicum baccatum* var. *pendulum*. *Euphytica* 29: 331-335.

Rao, L. G., Guns, E., Rao, A. V. (2003). Lycopene: Its role in human health and disease.

Rao, N.K. (2004). Plant genetic resources: Advancing conservation and use through biotechnology. *African J Biotech* 3 (2): 136-145.

Rehima, M. (2006). Analysis of Red Pepper Marketing: the Case of Alaba and Siltie in Snnprs

Rohanizah, A. R., Ishak, M. (2012). Phytochemical Contents of *Capsicum Frutescens* (Chili Padi), *Capsicum Annum* (Chili Pepper) and *Capsicum Annum* (Bell Peper) Aqueous Extracts. *International Conference on Biological and Life Sciences*; IPCBEE vol.40.

Rylski, I. (1972). Effect of early environment on flowering in pepper (*Capsicum annuum* L.). Journal of the American Society for Horticultural Science 97: 648-651.

Rylski, I., Spigelman, M. (1982). Effects of different diurnal temperature combinations on fruit set of sweet peppers. *Scientia Horticulturae* 17: 101-106.

Saidu, A. N., Garba, R. (2011). Antioxidant activity and phytochemical screening of five species of capsicum fruits. *International Research Journal of Biochemistry and Bioinformatics* (ISSN-2250-9941) Vol. 1(9): 237-241.

Sanatombi, K., Sharma, G.J. (2006). In vitro regeneration and mass multiplication of *Capsicum annuum* L. *Journal of Food Agricultural Environment* 4: 205-208.

Sandar, M., Teerayoot, G. (2013). Relationships of Soybean [*Glycine max* (L.) *Merrill*] Accessions Based on Physiological and Agro-morphological Traits. *International Journal of Chemical, Environmental & Biological Sciences* (IJCEBS) Volume 1(2): ISSN 2320–4079.

Seleshi, D. (2011). Evaluation of elite pepper varieties (*Capsicum* species) for growth, dry pod yield and quality under Jimma condition, South West Ethiopia:

Sharoba, A.M. (2009). Producing and Evaluation of Red Pepper Paste as New Food Product. *Fo. 151 Annals of Agric. Sci., Moshtohor*, Vol. 47(2): Fo. 151-165, (2009).

Sherakat, D. S. (2009). Several Culinary and Medicinal Herbs Are Important Sources of Dietary Antioxidants. *The J. Nutrit*., 133: 286-390.

Simonne, A. H., Simonne, E. H., Eitenmiller, R. R., Mills, H. A., Green, N. R. (1997). Ascorbic acid and provitamin A contents in unusually colored bell peppers (*Capsicum annum* L.). *J. Food Compo. Anal*. 10:299–311.

Singh, R. J. (1993). Plant cytogenetics. CRC Press, Boca Raton, 391p.

Singh, R.H., Rankine, L.B., Seepersad, G. (2006). The Caricom Regional Transformation Programme for Agriculture Market Intelligence Report; Hot Peppers.

Sreelathakumary, I., Rajamony, L. (2004). Variability, heritability and genetic advance in chilli (*Capsicum annuum* L.). *J. of Tropical Agr*. 42.

Sudre, C. P., Gonçalves, L. S. A., Rodrigues, R., Amaral, A. T. D., Riva-Souza, E. M., Bento, C. D. (2010). Genetic variability in domesticated Capsicum spp as assessed by morphological and agronomic data in mixed statistical analysis. *Genet. Mol. Res*. 9 (1): 283-294 (2010).

Surh, Y. J., Seoul, S. K. (2002). Anti-Tumor Promoting Potential of Selected Spice Ingredients with Oxidative and Anti-Inflammatory Activities. *Food and Chemical Toxicology*, Vol. 40, No. 8:1091-1097.

Tay, D. C. S., (1989). Genetics resources of tomato and pepper at AVRDC. In Tomato and pepper production in the Tropics. Proceedings of the International Symposium on Integrated Management Practices, Asian Vegetable Research and Development Center, Taiwan, pp: 10-12.

Ted, R., Kevin, C., Glenn, T., Alton, A., Amjad, A. (2012). Capsaicin Content of Hawaii-grown Chili Peppers.

The Columbia Encyclopedia (2008). Sixth edition New York, NY: Columbia University Press; [http://www.encyclopedia.com/topic/plant_breeding.aspx].

Thomas, L. P., Watson, M. A. (1988). Leaf removal and the apparent effects of architectural constraints on development in *Capsicum annuum*. *American Journal of Botany* 75: 840-843.

Thomas, T. A., Mathur, P. N. (1991). Germplasm Evaluation and Utilization. Published by the International Board for Plant Genetic Resources, Regional Office for South and Southeast Asia, c/o NBPGR, Pusa Campus, New Delhi 110 012, India.

Thurling, M., Ratinam, M. (1989). Early Generation Selection for Grain Yield in Narrow-leaf Lupin (Lupinus angustifolius L.). *Plant Breeding* volume 102 : 286-295.

Tong, N., Boland, P. W. (2003). Observations on interspecific compatibility and meiotic chromosome behavior of *Capsicum buforum* and *C. lanceolatum*. *Genetic Resources and*

Tsai, S.Y., Huang, S. J., Lo, S. H., Wu, T. P., Lian, P.Y., Mau, J. L. (2009). Flavour components and antioxidant properties of several cultivated mushrooms. *Food Chemistry*, 113(2): 578–584.

Upadhyaya, H. D., Gowda, C. L. L., Sastry, D.V.S.S.R. (2008). Plant genetic resources management: collection, characterization, conservation and utilization. *Journal of SAT Agricultural Research* 6.

Usman, A. (2013). Genetic analysis of resistance to rosette disease of groundnut (*Arachis hypogaea* L.).

Van den Berg, H. , Faulks, R., Granado, H. F., Hirschberg, J., Olmedilla, B., Sandmann, G. Southon, S., Stahl, W. (2000). *Journal of the Science of Food & Agriculture* 2000; 80(7):880-912.

Vera-Guzman, A. M., Chavez-Servia, J. L., Carrillo-Rodriguez. J. C., Lopez, M. G. (2011). Phytochemical evaluation of wild and cultivated pepper (*Capsicum annuum* L. and *C. pubescens* Ruiz & Pav.) from Oaxaca, Mexico.

Vinod, K., Nandan, R., Srivastava, K., Sharma, S. K., Kumar, R, Kumar, A. (2013). Parameters and correlation study for yield and quality traits in tomato (*Solanum lycopersicum l.*). *Plant Archives Vol*. 13 No. 1, 2013 pp. 463-467.

Wadood, A., Ghufran, M., Jamal, S. B., Naeem, M., Khan, A. (2013). Phytochemical Analysis of Medicinal Plants Occurring in Local Area of Mardan. *Biochem Anal Biochem* 2: 144.

Walsh, B. M., Hoot, S. B. (2001). Phylogenetic relationships of *Capsicum* (*Solanaceae*) using DNA sequences from two noncoding regions: The chloroplast *atpB-rbcL* spacer region and nuclear *waxy* introns. *International Journal of Plant Sciences* 162: 1409-1418.

Walter, H.G. (1986). Pepper breeding. In: M.J. Bassett (Ed), Breeding vegetable crops, pp. 67–134. Avi Publishing Company, Connecticut.

Watkins, J. T., Cantliffe, D. J. (1983a). Hormonal control of pepper seed germination. *HortScience* 18: 342-343.

Weiss, E. A. (1971). *Castor, Sesame and Safflower,* Leonard Hill Books, London, UK, 1971.

Wolfe, K. L., Liu, R. H. (2008). Structure-Activity Relationships of Flavonoids in the Cellular Antioxidant Activity Assay. *J. Agric. Food Chem.* 56: 8404-8411.

Woodall, A. A., Britton, G., Jackson, M. J. (1997). Carotenoids and protection of phospholipids in solution or in liposomes against oxidation by peroxyl radicals: Relationship between carotenoid structure and protective ability. *Biochim Biophys Acta* 1997; 1336:575–586.

XLSTAT Statistical Software (2015). *https://www.xlstat.com/*.

Yahia, E. M., Contreras, P.M., Gonzalez, A. G. (2001). LWT-Food Sci. Tech., 34:452-457.

Zhang, D., Hamauzu, Y. (2003). Phenolic compounds, ascorbic acid, carotenoids and antioxidant properties of green, red and yellow bell peppers. *Food, Agriculture and Environment* 2:22-27.

Zuknik, M. H., Norulaini, N. A., Omar, A. K. M. (2012). Supercritical carbon dioxide extraction of lycopene: A review. *Journal of Food Engineering*, 112(4), 253–262.

APPENDICES

APPENDIX 1

Mean squares from the analysis of variance of reproductive and fruit quality traits for 17 pepper genotypes under field conditions

S. of Variation		Mean Squares							
	Df	DTF	DtF	FFS	DFR	FL	FW	FWT	NOS
Rep.	2	221.25	54.84	32.49*	101.25	4.92	0.11	0.00048	78.47
Genotype	16	460.65*	330.63*	252.75*	243.31*	19.80*	0.26*	0.06052*	753.28
Residual	32	24.71	35.28	60.74	33.86	0.39	0.039	0.00099	32.96
Total	50	172.07	130.56	121.05	103.58	6.78	0.11	0.02	265.28

*Significant (P< 0.001), ▪ significant (P≤ 0.05), DTF= days to 50% fruiting, DtF= days to 50% flowering, FFS=days to first fruit set, DFR=days to first fruit ripe, FL=fruit length, FW= fruit width, FWT= fruit wall thickness, NOS = number of seeds

APPENDIX 2

Mean squares from the analysis of variance of reproductive and fruit quality traits for 17 pepper genotypes under greenhouse conditions

S. of Variation		Mean Squares							
	Df	DTF	DtF	FFS	DFR	FL	FW	FWT	NOS
Rep.	2	0.76	6.73	66.84	45.90	0.022	0.045	0.024	7.31
Genotype	16	1307.66*	1317.66*	804.06*	553.66*	67.979*	0.687*	0.031	1967.88*
Residual	32	20.35	16	45.32	56.01	0.789	0.119	0.016	20.50
Total	50	431.51	432.16	288.98	214.85	22.259	0.298	0.021	643.14

*Significant (P< 0.001), ▪ significant (P≤ 0.05) DTF = days to 50% fruiting, DtF = days to 50% flowering, FFS=days to first fruit set, DFR=days to first fruit ripe, FL=fruit length, FW= fruit width, FWT= fruit wall thickness, NOS = number of seeds,

APPENDIX 3

Mean squares from the analysis of variance of reproductive and fruit quality traits for 17 pepper genotypes (combined)

S. of Variation		Mean Squares							
	Df	DTF	DtF	FFS	DFR	FL	FW	FWT	NOS
Rep.	2	119.01	11.77	31.53	38.15	2.148	0.07006	0.0134	64.71
Genotype	16	1515.48*	1303.19*	879.70*	706.56*	77.423*	0.6439*	0.0433*	2159.68*
Env.	1	876.48*	155.65▪	1320.48*	3030.75*	280.75*	3.8698*	0.0061	1809.37*
E x G	16	252.83*	345.11*	177.11*	90.41▪	10.36*	0.2996*	0.0482*	561.48*
Residual	68	27.74	25.94	52.83	46.62	0.657	0.07968	0.0089	27.68
Total	101	307.48	280.129	216.060	187.65	17.157	0.24124	0.02052	467.626

*Significant (P< 0.001), ▪ significant (P≤ 0.05), DTF= days to 50% fruiting, DtF= days to 50% flowering, FFS=days to first fruit set, DFR=days to first fruit ripe, FL=fruit length, FW= fruit width, FWT= fruit wall thickness, NOS = number of seeds

APPENDIX 4

Mean squares from the analysis of variance of vegetative and yield quality traits for 17 pepper genotypes under field conditions

S. of Variation	Df	Mean Squares							
		NOF	YTH	NOL	SG	PH	CW	CCF	CCH
Rep.	2	1568	2.22	5648	0.018	33.6	45.22	23.37	607.5
Genotype	16	9163▪	4.92	31429*	0.081*	234.6▪	275.69▪	1661.94*	1742.1*
Residual	32	3801	2.70	4467	0.022	74.27	87.42	95.17	360
Total	50	5427.42	3.39	13.14	0.041	123.95	145.98	593.66	812.18

*Significant (P< 0.001), ▪ significant (P≤ 0.05), NOF = number of fruit per plant, YTH = yield (ton/ha), NOL = number of leaves, SG = stem girth , PH = plant height, CW = canopy width, CCF = chlorophyll content at flowering stage, CCH = Chlorophyll content at harvest

APPENDIX 5

Mean squares from the analysis of variance of vegetative and yield quality traits for 17 pepper genotypes under greenhouse conditions

S. of Variation		Mean Squares							
	Df	NOF	YTF	NOL	SG	PH	CW	CCF	CCH
Rep.	2	1444.5	13.85	700.9	0.44	31.62	104.99	134.59	186.03
Genotype	16	3181.4*	132.35*	33888.1*	0.72	2274.74*	2035.36*	223.2*	1626.9*
Residual	32	435.5	6.08	425.0	0.77	78.49	87.72	11.37	72.11
Total	50	1354.6	46.79	11144.2	0.74	779.42	711.66	84.08	574.19

*Significant (P< 0.001), ▪ significant (P≤ 0.05) NOF = number of fruit per plant, YTH = yield (ton/ha), NOL = number of leaves, SG = stem girth, PH = plant height, CW = canopy width, CCF = chlorophyll content at flowering stage, CCH = Chlorophyll content at harvest,

APPENDIX 6

Mean squares from the analysis of variance of vegetative and yield quality traits for 17 pepper genotypes (combined)

S. of Variation		Mean square							
	Df	NOF	YTH	NOL	SG	PH	CW	CCF	CCH
Rep.	2	864	3.26	1458	0.287	23.01	9.70	133.22	150.6
Genotype	16	9330*	82.62*	36046*	0.401	1701.86*	1459.61*	1490.4*	2881.9*
Env.	1	412	1121.41*	6474	1.46	114885.28*	65550.54*	49764.44*	48.8
E x G	16	3014	54.65*	29270*	0.39	807.48*	851.44*	394.78*	487.1▪
Residual	68	2119	4.65	2489	0.39	73.81	86.84	54.78	226.7
Total	101	3361.5	35.95	12087	0.4009	1584.69	1073.59	828.24	686.81

*Significant (P< 0.001), ▪ significant (P≤ 0.05), NOF = number of fruit per plant, YTH = yield (ton/ha), NOL = number of leaves, SG = stem girth, PH = plant height, CW = canopy width, CCF = chlorophyll content at flowering stage, CCH = Chlorophyll content at harvest

APPENDIX 7

Mean squares from the analysis of variance of antioxidant properties for 17 pepper genotypes under field conditions

S. of Variation	Df	Mean Squares						
		IC_{50}	VA	LC	GA	BC	RA	FC
Rep.	2	0.0068	21.33	0.0029	8.74	0.035	11.41	0.0066
Genotype	16	0.2979	85.87*	0.0031*	30.73*	0.027*	51.48*	0.1192*
Residual	32	0.0000	1.39	0.00012	1.26	0.004	1.56	0.0082
Total	50	0.0956	29.22	0.0012	10.99	0.013	17.93	0.0436

*Significant (P< 0.001), ▪ Significant (P≤ 0.05), IC_{50} value, VA= vanillic acid content, LC = Lycopene content, GA = gallic acid content, BC = beta carotene content, RA = Rosmarinic acid, FC = total flavonoid content

APPENDIX 8

Mean squares from the analysis of variance of antioxidant properties for 17 pepper genotypes under greenhouse conditions

S. of Variation	Df	Mean Squares						
		IC_{50}	VA	LC	GA	BC	RA	FC
Rep.	2	0.0068	0.98	0.014	0.38	0.023	0.6	0.0098
Genotype	16	0.2964	78.39*	0.019	27.73*	0.104▪	45.7*	0.0446*
Residual	32	0.0000	2.11	0.016	1.18	0.048	1.058	0.0035
Total	50	0.0951	26.48	0.017	9.64	0.065	15.33	0.0169

*Significant (P< 0.001), ▪ significant (P≤ 0.05), IC50 value, VA= vanillic acid content, LC = Lycopene content, GA = gallic acid content, BC = beta carotene content, RA = Rosmarinic acid, FC = total flavonoid content

APPENDIX 9

Mean squares from the analysis of variance of antioxidant properties for 17 pepper genotypes (combined)

S. of Variation	Df	Mean Squares						
		IC_{50}	VA	LC	GA	BC	RA	FC
Rep.	2	0.014	9.95	0.0021	5.57	0.041	7.91	0.01274
Genotype	16	0.32	46.06*	0.0104	16.41*	0.088*	27.20*	0.09880*
Env.	1	0.801	381.73*	0.2024*	140.92*	0.17▪	243.92*	0.00009
E x G	16	0.27	118.20*	0.0114	42.05*	0.044	69.99*	0.06505*
Residual	68	0.00	2.31	0.0079	1.42	0.026	1.58	0.00579
Total	101	0.102	31.35	0.0108	11.61	0.04	18.88	0.02999

*Significant ($P< 0.001$), ▪ significant ($P\leq 0.05$), IC50 value, VA= vanillic acid content, LC = Lycopene content, GA = gallic acid content, BC = beta carotene content, RA = Rosmarinic acid, FC = total flavonoid content