INFLUENCE OF GENOTYPE, FRUIT MATURITY AND POST HARVEST RIPENING ON GERMINATION AND EARLY SEEDLING PERFORMANCE IN PEPPER (*Capsicum sp.)*

BY

PRINCE APPIAH EBUREY
(10555212)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY IN SEED SCIENCE AND TECHNOLOGY.

WEST AFRICA CENTRE FOR CROP IMPROVEMENT

COLLEGE OF BASIC AND APPLIED SCIENCES

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DECLARATION

I, Appiah Eburey Prince, do hereby declare that this thesis has not been submitted to any other university for a degree. The report herein presented is the result of my own investigation. All references to other works as a source of information have been duly acknowledged.

APPIAH EBUREY PRINCE SIGNATURE……………………………

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PROF. E. T. BLAY SIGNATURE……………………………

(SUPERVISOR) DATE……………………………………

PROF I. K. ASANTE SIGNATURE……………………………

(SUPERVISOR) DATE……………………………………

DR. AGYEMANG DANQUAH SIGNATURE……………………………

(SUPERVISOR) DATE……………………………………

ABSTRACT

An experiment to evaluate the influence of fruit maturity and after ripening on germination and early seedling performance in Pepper (*Capsicum spp.*) was conducted at the research field of the department of Crop Science, University of Ghana, Legon between November 2016 and May 2017. Five pepper genotypes were grown on the field in a Randomized Complete Block Design and seeds extracted at two maturity stages namely, physiologically matured and full red ripe stages. Seeds were extracted from fuits at physiological maturity and at fully ripe stage. Number of seeds per fruit, seed dry weight, food reserves (carbohydrate, protein, fat) content in seeds, total phenols and total flavonoids content in seeds were determined in the laboratory. A second experiment arranged in a completely randomized design to evaluate germination of seeds harvested from pepper fruits at the different maturity stages was conducted on a Jacobsen germination table in the laboratory. The genotype Shito Adope obtained the highest germination percentage of 88.5%, which was significantly higher than Bird beak (83.5%), Legon 18 (68.5%), Ojemma (47.25%) and Red Scotch Bonnet (13%) for seeds harvested at full ripe stage whiles for seeds from physiologically mature fruits that had gone through after ripening, Shito Adope had a germination percentage of 68% which was significantly different from Bird beak (46%), Legon 18 (28.5%), Ojemma (23.5%) and Red Scotch Bonnet (3.75%). A third experiment arranged in a completely randomized design was conducted to evaluate early seedling performance of seeds of the genotypes harvested at the different maturity stages. From the results obtained, it was observed that harvesting stage significantly affected seed yield (number of seeds / fruit), seed quality and early seedling performance in all the genotypes studied. Seeds from fully ripe fruits showed higher germination and early seedling performance for all five genotypes studied. Seeds from fully ripe fruits performed significantly better than those taken from physiologically mature fruits that had gone through after ripening in terms of emergence percentage and early seedling performance as well as food reserve composition. Correlation analysis showed positive associations in all food reserve components and percentage germination and emergence as well as seedling vigour. However, there were negative correlations between phytochemicals present in seeds and percentage germination, percentage emergence as well as seedling vigour. For better germination and vigour, extraction of pepper seeds from half ripe fruits should be avoided.

DEDICATION

I dedicate this work to God Almighty and to the memory of my late mother, Rose Owusu-Ansah.

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

µl	Microliter
ºC	Degree Celsius
ºF	Degree Fahrenheit
% G	Germination percentage
% E	Emergence percentage
ANOVA	Analysis of Variance
CV (%)	Coefficient of variation expressed as percentage
EU	European Union
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization databases
GAE	Gallic Acid Equivalent
ISTA	International Seed Testing Association
KAE	Kaemferrol content
LSD	Least significant difference
MT	Metric tonnes
N	Nitrogen
NBP	Number of branches per plant
NLP	Number of leaves per plant
Nm	Nanometer
NPK	Nitrogen Phosphorus Potassium
PHT	Plant height
PPRSD	Plant Protection and Regulatory Services Directorate
Pro	Protein content
QUE	Quercetin content
RL	Seedling root length
RMG	Regional Marketing Group
Ru	Rutin content

SG	Stem girth
sg	Seedling girth
SL	Seedling shoot length
TPhe	Total Phenol
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture
WAS	Weeks after Sowing
WAT	Weeks after Transplanting
WP	Wettable Powder

LIST OF TABLES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Pepper (*Capsicum sp*) belongs to the family *solanaceae* together with crops such as tobacco, tomatoes, potatoes and eggplant (Bosland *et al.*, 1996; Dias *et al.*, 2013). The origin of the crop is Central and South America (Purseglove *et al.*, 1981; Bosland *et al.*, 1996) from where it was distributed to other parts of the world. Pepper, considered to be the first spice to have been used by humans is cultivated worldwide and is a major component of many cuisines. Archaeological evidence predates the existence of pepper and other fossil foods from 6000 years ago (Hill *et al.*, 2013). Among species of the *Capsicum* genus that are domesticated (*C. annuum, C. frutescens, C. chinense, C. pubescens* and *C. baccatum)*, *C. annuum* is the most cultivated worldwide (Andrews, 1984). Pepper is a small perennial shrub with white or greenish-white corolla, one or more pedicels at a node with varying fruit shapes and sizes (Norman, 1992). The maturity is relatively quick, between 3-4 months. In West Africa, hot pepper is a major vegetable and is an important constituent of local dishes. Recently, the crop is grown for export to Europe and has become an important foreign exchange earner. Sweet pepper, also known as bell pepper or Paprika, are grown for consumption in the urban areas and also for export.

In Ghana, pepper is often cultivated as an intercrop in home gardens and near settlements but recently it is cultivated on large scale by both peasant and commercial farmers. The derived savanna and northern savanna agro-ecologies with an annual rainfall of 600-1250 mm are best suited for hot pepper production according to Norman (1992). It is an unavoidable ingredient in many dishes worldwide.

Earlier researchers have noted that β-carotenoids, vitamins A and C present in pepper are potent antioxidants that destroy free radicals (Simonne *et al.*, 1997).

Pepper is one of the four most widely cultivated vegetables in Ghana in terms of production volume, and has always been part of the country's agriculture (Schippers, 2000). It is one of the major vegetable crops exported by 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) reported that, the production of peppers 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 for pepper has been increasing yearly by 17 percent on average since 2000 (MiDA, 2010). Due to higher pungency and flavour of cultivars grown in Ghana, there is a high demand for chili pepper from Ghana compared with chili peppers from other countries (MiDA, 2010).

Currently there is limited export of vegetables from Ghana to neighboring countries. Main reasons for the limited export to neighboring countries are the high demands on the local market, poor facilities for regional export, lengthy border checks and lack of demand for the Asian type of vegetables in the neighboring countries (Saavedra *et al.,* 2014).

In the production of peppers, major constraints often encountered include environmental stresses such as high humidity, little/ too much rainfall, poor soil fertility and pH, high temperatures, pests and diseases attack (Adu-Fosu and Fiscian, 2012). Other constraints still include limited access to quality seeds, bad agronomic practices and lack of knowledge in improved farm management techniques by small-holder farmers which contribute to low production of chili (AVRDC, 1990).

The production of vegetable crops is greatly influenced by the physiological quality of the seed (Gurusamy, 1999). The quality of seed produced depends on various factors such as soil, climate, cultural practices and, more importantly, on seed harvest time to obtain maximum seed quality (Delouche, 1980). For instance in fleshy fruits as tomato and pepper, delayed harvesting results in increased seed moisture content which may lead to rapid ageing (Welbaum, 1993; Oluoch and Welbaum 1996; Bradford, 2004).

In a number of different species, such as cucumber, pepper and muskmelon, harvested fruits have been held for an after-ripening period, so that viability and vigour levels increased and immature seeds reached the quality of mature seeds (Barbedo *et al.,* 1994; Nandeesh *et al.,* 1995; Cavero *et al.,* 1995; Welbaum and Bradford, 1988). Thus both fruit maturity stage and length of ripening period may affect seed quality.

1.2 Problem Statement

It has been reported that pepper producers in Ghana are realizing about half the percentage of the attainable yields (MiDA, 2010). This is due to various production constraints prominent among which is the lack of good planting materials (seeds) that are well adapted to the local environment and meet export demands (Nkansah *et al.*, 2011). Fruit ripeness at the time of seed extraction has been pointed out as a factor that can affect pepper seed quality and germination behavior (Cavero et al., (1995). Randle and Honma (1981) found that the riper the fruit that provided the seeds, the earlier germination occurred. Edwards and Sundstrom (1987) working with cultivar 'Tabasco' (*Capsicurn frutescens L.*) observed that seeds taken from fully ripe fruits had greater germination rates than those obtained from orange-coloured fruits.

Blay *et al.,* (1999) reported that post-harvest ripening also improved the total percentage germination of seeds extracted from fruits harvested at the white or yellow stages, but decreased the percentage germination in seeds from fruits harvested at the red-ripe stage in eggplant (*Solanum gilo)*. Postharvest ripening could be interesting in augmenting seed quality when fruits were not harvested at fully ripe stage (Quagliotti *et al.*, 1981).

Determining the optimum harvest time for seeds that mature within a fleshy fruit is especially important. The time of the attainment of maximum seed quality during development and its association with seed and fruit characteristics however, show great variation among cultivars and between locations. The recent increase in land acreage under cultivation calls for the adoption of efficient strategies for producing good-quality seeds.

1.3 Objectives

The main objective of this study is therefore to determine the effect of genotype maturity and postharvest ripening on seed production and seed quality of five genotypes of *Capsicum spp*.

The specific objectives of the study were to:

- Evaluate vegetative and reproductive performance of genotypes on the field.
- Evaluate seed production of genotypes on the field.
- Evaluate germination and vigour of the seeds of the five genotypes.
- Assess the influence of stage of fruit ripening at harvest, and after ripening on seed yield per fruit, germination and early seedling growth.
- Determine the phytochemical composition of seeds of genotypes and ascertain its contribution to seed quality.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Chilli Pepper

Chilli pepper (*Capsicum frutescens* L.), also known as hot pepper, is an annual herb belonging to the genus Capsicum, under the Solanaceae family (Russo, 1996). It is believed to have originated in South America, more specifically, Mexico (Pickersgill, 1997; De Lannoy, 2001). Chilli is now widely grown throughout the tropics, sub-tropics and the warmer regions of the world (George, 1985).

The world production of fresh chilli pepper was 31.2million mt in 2012, from an estimated 2.0 million hectares of land (FAOSTAT, 2013). The world's top three producers of fresh chilli pepper in 2012 were China, Mexico, and Turkey with a production volume of 16.0 million mt, 2.4 million mt and 2.1 million mt, respectively, (FAOSTAT, 2013). Nigeria and Ghana ranked 8th and 25th respectively in the world and the two are also the leading chilli producers in West Africa with a production volume of 500,000 MT and 110,000 MT, respectively, in 2012 (FAOSTAT, 2013).

2.2 Importance and Uses of Chilli Pepper

Chilli is widely grown primarily for its fruits and seeds, but it is used in several ways based on its hotness and color. The seeds contain capsaicin which is the main active ingredient and considered to have medicinal uses (Messiaen, 1992). Berke *et al.* (2005) reported that consumer preference for pepper fruits are considered according to the shape, color and degree of pungency. The fruits of chilli can be cooked or eaten raw as vegetable in soups and stews and the dried powder can be used as spice for seasoning and flavoring (Gibbon and Pain, 1985; Boateng, 2006). Nutritionally, chilli pepper is an excellent source of vitamins (A, B_2, B_6, C, and K) and essential minerals (potassium, phosphorus, calcium, iron, and zinc) (Bosland and Votava, 2000; Norman, 2002).

Medicinally, chilli is used in the prevention and treatment of cold and fever (Udoh *et al*., 2005). Some other uses include easing the digestion process by stimulating the gut, thereby helping to prevent constipation, and relieve pain (Patwardhan *et al*., 2010). The crop contains high content of capsaicin ($C_{18}H_{27}N0_3$), an alkaloid which imparts the pungency or spicy taste. Capsaicin in pepper is a major ingredient in developing pain-killers as reported by Patwardhan *et al*., (2010). Chili pepper based extracts are fast becoming popular in many integrated pest management programmes in controlling common agricultural pests (Oparaeke *et al*., 2005) and in the manufacture of protective sprays to combat criminal activities. The crop is a foreign exchange earner in Ghana, and is being exported to the European Union (EU) with an annual export increase of 17 per cent since the year 2000 (MiDA , 2010).

2.3 Botanical Classification and Floral Biology

Botanically, chilli pepper (*Capsicum frutescens* L.) is a fruit-bearing vegetable that belongs to the Solanaceae family along with tomato and eggplant (Hadfield, 1993). The crop is generally self-pollinating, although cross-pollination is also common (Delaplane and Mayer, 2000). The fruit is non-climacteric which implies that it does not ripen once harvested unripe (Díaz-Pérez *et al*., 2007). The genus Capsicum consists of twenty-five wild species and five domesticated species

(*Annuum, Baccatum, Chinense, Frutescens and Pubescens*) which have been transformed into the immense diversity of chilli peppers grown around the world.

The stem of chilli is woody at the base and the leaves which are unequal in shape may be oval or oblong, exhibiting acute apex, 1.5-10 cm in length and 0.5-2.5 cm in width (Tindall, 1983). The plant bears small flowers, singly or in groups of 2-3, with long pedicels, erect and 1.5-2.5 cm in length. Different cultivars have varying pedicel length ranging from 3 to 8 cm (Berke, 2000). The calyx of the chilli flower is small, 5-toothed, yellow green, with petals that may be yellow or green white (Tindall, 1983). The crop produces two or more fruits, which can be small and narrow, up to 2-3 cm in length and 7-10 mm in diameter depending on cultivar. They may be red or yellow when ripe and are extremely pungent (Gibbon and Pain, 1985; Rice *et al*., 1986).

2.4 Environmental Requirements of Chilli Pepper

Temperature and rainfall are the two main factors that account for seasonal variations in growth and yield of chilli across many regions (Karikari and Mathew, 1990). Chilli pepper grows best under tropical and subtropical climates. The optimum day temperatures for chilli pepper growth ranges from 20 to 30°C (AVRDC, 2005). A daytime temperatures exceeding 30°C can be tolerated, as long as night temperatures are within 21–24°C (Acheampong, 2007). A fall in temperature below 15°C or above 32°C for extended periods will cause reduction in growth and yield of chilli (AVRDC, 2005).

Chilli grows best in loam or silty-loam soil with good water-holding capacity. The crop can however grow on many soil types which are well drained and within a pH range of 5.5 and 6.8 (AVRDC, 2005). During the growing season, about 600 mm of water is required either as rain or irrigation. Heavy rainfall during the flowering period causes flower shedding and poor fruit setting, and during the ripening period rotting of fruits; while too little may lead to flower and fruit drop (van Gastel *et al*., 1996; FAO, 2013). Dry conditions also result in premature small-sized fruit set, which leads to reduced yields (Bosland and Votava, 1999).

2.5 Management and Cultural Practices

2.5.1 Sowing and Raising of Seedlings

Good land preparation is essential as it provides soil conditions suitable for rapid and uniform seedlings establishment, as well as good root penetration which subsequently leads to optimal growth and development of crops (Page *et al*., 2002). Site selection is very important for optimum production. Site previously cultivated to any member of the *Solanaceae* family during the previous two seasons should be avoided to minimize pest and disease infestation. A week prior to transplanting, the site should be cleared, ploughed and harrowed, followed by field layout. Depending on the history of the site, a weedicide should be applied prior to transplanting of seedlings to control obnoxious weeds (Page *et al*., 2002). In addition to synthetic fertilizers, the application of organic manure improves soil structure and enhances the growth of soil micro-flora and fauna (Coertze and Kistner, 1994).

Variation in germination depends on a number of factors including variety, seed quality, and soil mixture. In order to attain optimum germination, seeds should be sown on a well-drained, loamy soil mix with peat or compost. Seeds should be broadcasted lightly or drilled on a seedbed and covered lightly with soil (about 1 cm deep). If the seedlings were grown in shade, they should be hardened by gradually exposing them to direct sunlight over 4–5 days prior to transplanting

(AVRDC, 2005). Under good conditions, seedlings are ready for transplanting four to five weeks after sowing, when the seedling developed 4–5 true leaves.

2.5.2 Weed control

Chilli establishes slowly and cannot compete with aggressive weeds. Generally, weeds compete with crops resulting in reduced yields and poor quality crops. Weeds can also harbour harmful insects and diseases (Chandran, 2009). Method of weed control can be either by physical means or chemical means (Chandran, 2009). Natural organic mulches such as rice straw besides controlling weeds also conserve soil moisture and add organic matter to the soil. Weed control can also be achieved through the use of wide range of herbicides. However, good weed control in peppers should start before the crop is planted (Bullock*,* 2011).

2.5.3 Pests and disease of chilli pepper

Chilli pepper is a more robust crop compared to tomato, garden egg and sweet pepper. The crop is however affected by a number of pests and pathogens resulting in considerable loss economically (Dagnoko *et al*., 2013). Pest and disease infestation not only lead to reduction in yield, but also affects the quality of seeds. Most diseases can be transmitted in or on pepper seeds. The most prevalent and economically important diseases of pepper caused by bacteria are bacterial leaf spot (*Xanthomonas campestris,* var vesicatoria. Doidge), bacterial wilt (*Ralstonia solanacearum.* Smith) and bacterial soft rot (*Erwinia carotovora.* Smith) (Cheewawiriyakul *et al*., 2006; Pernezny *et al.*, 2003). Diseased plants can exhibit a variety of symptoms, including abnormal leaf growth, color distortion, stunted growth, shriveled plants and damaged fruits (James *et al.*, 2010; Dafalla, 2001). In Ghana, the diseases of economic importance to chilli pepper growers are fruit rot, damping off, anthracnose, bacterial wilt, pepper veinal mottle virus and leaf curl (Karikari and Mathew (1990).

The major pests of pepper common in West Africa include thrips (*Frankliniella* spp.), aphids (*Aphis* spp.*),* whitefly (*Bemisia tabaci* Gennadius) and root knot nematodes (*Meloidogyne* spp). The thrips usually feed on the leaves, the flowers or fruits while the aphids feed on young leaves and shoots. The whiteflies and root knot nematodes feed on the leaves and roots respectively. Others include the Mediterranean fruitfly (*Ceratitis capitata.* Wiedemann) which causes damage to the fruit by feeding on the fruit flesh and red spider mites (*Tetranychus* spp) which feed on the leaves, as well as fruit borers (*Lepidopterae* spp). Aside the damages pests cause to the plants by direct feeding, some of the pests such as whiteflies, aphids, thrips and nematodes are also vectors of viruses (James *et al.*, 2010). Early identification and correct diagnosis are key steps in managing potential pest and disease problems. The use of resistant cultivars or pathogen-free seeds if available, is one of the primary measures to minimize the problem (Bessin, 2014).

2.5.4 Harvest and Post-Harvest Processing

Chilli peppers are grown as annuals and harvesting occurs about 3 months after planting. Flowering takes place 45 to 60 days after transplanting and yield continues for several months depending on cultivar and optimum environmental conditions. For fresh use, chili peppers can be harvested either at physiological maturity or at the fully ripe stage (Berke *et al.*, 2004). However, best quality seeds are obtained from fully ripened fruits. To obtain quality seeds, fruits showing signs of diseases should be sorted out after harvest. Early harvesting results in low seed germination rate, while harvesting too late will lead to poor quality fruits and seeds (AVRDC, 2005).

Shelf-life is prolonged by storing fresh fruits in cool, shaded, dry place at an ambient temperature of 28°C and 60% relative humidity (Kaaya and Kyamuhangire, 2010). Fresh chilli fruits should not be washed unless they are to be kept in a cool environment (10°C) to avoid fresh fruit spoilage caused by anthracnose or other fungal or bacterial diseases (Biles *et al*., 1993).

Fresh chilli fruits contain 65-80% moisture at harvest, and must be reduced to about 8-10% to prolong the shelf-life (Biles *et al*., 1993). Processing of chili pepper seeds can be carried out by extracting the seeds from fresh or dried fruits either by hand or mechanical maceration followed by drying. Sun-drying is the common practice of processing chilli in many developing countries and is achieved by spreading the produce on clean dry polythene sheets or a concrete floor to reduce the moisture content to about 8 -10 %. If available, a solar dryer can be used but require fairly constant sunshine. Rainfall and cloudy weather increases the drying time and the risk of post-harvest spoilage (Rashid, 1999).

2.6 Storage

Freshly harvested pepper fruits must be stored between 7°C and 10°C at 95% relative humidity. Under these conditions, the fruits can be kept for a period of 3-5 weeks. Peppers are sensitive to chilling injury when exposed to temperatures below 7°C and symptoms include pitting and water-soaked tissue (Kitinoja and Kader, 2004). A storage temperature above 13°C, accelerates ripening in chilli and predisposes the fruits to bacterial soft rot infection. In the absence of a cold storage facility, fruits should be sorted, packed, and marketed within 24 hours of harvest (Biles *et al*., 1993).

For sun-dried chilli fruits, the products should be packed in clean, dry polythene or woven bags and stored ensuring protection from dampness. Stacked bags should be kept 50-60 cm away from the wall to allow ventilation. Longer period of storage may however lead to fruit or seed deterioration (Varmudy, 2001).

Appropriate storage conditions for chilli seeds should be under controlled conditions; maintain a constant temperature and free from excess moisture in order to maintain their vitality for many years (TNAU, 2013). Temporary storage materials for chilli seeds are airtight sealed glass jar, metal can, foil envelope and plastic containers (AVRDC, 2000). To maintain seed viability, they should be stored in a cool, dark, dry place between 35-50°F.

2.7 Seed Quality

Seed marks the beginning of plant production, and it is a prerequisite for obtaining high yields of all plant species. Seed quality is essential to agricultural production as poor seed limits the potential yield of crop and reduces productivity. Seed of high quality should possess good physiological, biochemical and phyto-pathological properties in a seed lot (Miloševic and Zlokolica, 1996; ISTA, 2004). A seed possessing these quality attributes have greater prospects of good plant stand establishment and producing a good quality crop. According to van-Gastel *et al*., (1996) quality seed can be defined as seed of an improved variety which has varietal and physical purity, low moisture content, high germination and vigour, free from weeds and seed-borne pathogens, uniform, and properly processed for distribution to farmers. The main attributes of seed quality assessment are germination, seed vigour and seed health. In general, seed viability greatly depends on percent germination, the vigour of a given seed lot and the health status of the seed (Asuboah, 2007).

There are several seed quality parameters. However, the following basic ones can be briefly considered:

- ***Analytical purity***

Purity analysis indicates how much of the material in the seed lot is intact of the species named on the label or being examined. Analytical purity evaluates the cleanliness of the seed lot into pure seed, seed of other species, weed seeds and inert matter (ISTA 2007). Seeds considered as pure seeds must be without impurities such as broken seeds, chaff, weeds, and other foreign materials (ISTA 2007; Simwanza, 2012).

- ***Germination capacity***

Germination in a laboratory test is the emergence and development of seedlings from the seed embryo to a stage where those essential structures (root system; shoot axis; cotyledons; terminal buds and the coleoptile) which make up the seedlings indicate their ability to develop into normal plants under favourable conditions (ISTA, 2007). Although the test cannot precisely forecast field emergence, it indicates that under certain set conditions, a seed lot of relatively high quality will emerge better than a seed lot of poor quality (ISTA, 2007). Germination test is an important attribute in determining the viability of seed and to avoid planting seed of low viability, which may lead to crop failure (Kaaya and Kyamuhangire, 2010).

- ***Seed Vigour***

Vigour testing is an important aspect of seed quality, and it indicates the ability of a seed lot to establish seedlings in harsh growing conditions (Simwanza, 2012). According to ISTA (2009), seed vigour is 'the sum total of those properties of the seed which determine the activity and performance of the seed lot during germination and seedling emergence' related to the deterioration, which occurs in seed lot as it ages, not necessarily in time, but in its ability to carry out all the physiological functions that allow it to perform (ISTA, 2009). A number of tests have been developed such as the radical emergence test, accelerated ageing and conductivity test (ISTA, 2009). Results of vigor testing of a seed sample show the percentage of seeds that are viable in the sample, as well as the ability of such seeds to produce normal seedlings in unfavourable or adverse growing conditions comparable to those which may occur in the field (ISTA, 1995). Evaluation of results for vigour tests is mainly classified between vigorous and non-vigorous seedlings. Seed vigor testing is also used as an indicator of how long a seed lot can be stored (Durrant and Gummerson, 1990).

Seeds may be classified as viable in a germination test which provides optimum temperature, moisture and light conditions to the growing seedlings; however, they may not be capable of continuing growth and completing their life cycle under a wide range of field conditions. (ISTA, 2009). Miloševic and Zlokolica (1996) reported that a highly humid and warm environment prior to harvesting can also lead to loss in seed viability and vigor. Other factors likely to have an adverse effect on seed vigour include mechanical damage to seeds caused by harvesting or conditioning equipment, as well as unsuitable conditions in storage. Genetic factors such as hardiness of seed, resistance to diseases, and chemical composition of the seed also have an influence on seed vigour. Results of vigour tests can also be used in deciding whether the seed lots can be sown earlier in the season, when the occurrence of stressful conditions is possible, or it should be sown later, when the soil is warmer and the conditions become more favourable for germination and seedling growth (Miloševic and Cirovic, 1994).

➢ ***Moisture Content***

Moisture content is the key factor in determining the possibility of seed retaining its germinability from harvest to sowing time. High moisture content at harvest damages the seed coat, while during storage, it initiates fungal development, insect activity, heating and germination, which contributes to rapid seed deterioration. Low moisture content, on the other hand makes seed liable to mechanical damage during harvesting and processing (van-Gastel *et al*., 1996). Seed moisture is the foremost seed physical attribute that contributes to storage life (ISTA, 2007). A lower seed moisture content results longer shelf life. Short term storage can be achieved by drying the seeds to 7-8% moisture content while long term storage is possible by reducing the seed moisture even further to 6% (TNAU, 2013).

➢ ***Seed Health***

Seed health refers to the presence or absence of disease-causing organisms, such as fungi, bacteria and viruses, and animal pests, including nematodes and insects. Seed health testing is carried out in order to assess seed sanitary quality (ISTA, 2007). Laboratory detection of the absence or presence of micro-organisms can help to predict field performance of seed samples relative to emergence and disease produced in the next generation, including expected losses (FAO, 2006; Burkholderia *et al.,* 2007). Reduced germination, vigour and potential yield resulting from transmission of pathogens from seeds to plants has been reported when infected seeds are sown (van Gastel *et al*., 1996; Simwanza, 2012*)*. The greatest negative effect of seed-borne pathogens is contaminating areas that are disease-free. Thus seed-borne pathogens act as a primary source of inoculum for disease development (ISTA, 2007). Although seed-borne inoculum levels may be particularly low, the rate of increase may be rapid given favourable epidemiological factors such as bad agronomic practices (Burkholderia *et al.,* 2007). Seed infection usually occurs during three distinct physiological stages; seed production, seed development and seed maturation. Pathogens can be involved in all these phases of growth and can transmit from planted to the new crop, leading to a systemic infection capable of colonizing the seed (McGee, 1995).

2.8 Polyphenols and Food Storage Compounds in Pepper Seeds

Pepper contains a wide array of phenolic compounds essential for growth and development of the plant. These phenolic compounds play major functions in plants such as protecting the plants against UV light, preventing pest and pathogen attack, contributing to plant pigmentation and as structural material ensures stability in plants (Msaada *et al.*, 2014). The various categories of plant phenolic compounds including simple phenols, flavonoids, anthocyanins, lignans, lignins and tannins have similar antioxidant properties as β-carotene, Vitamins C and E (Surh and Seoul, 2002). Sroka and Cicowski (2003) reported that phenolic acids have the ability to remove free radicals. Gallic acid, rosmarinic acid, salicylic acid and vanillic acid are among the major phenolic acid groups present in plants. They are essential to human health because of their antioxidant, antibacterial, antiviral and anti-inflammatory properties (Klem *et al.*, 2000).

Peppers are also rich in the flavonoids, which are the most abundant polyphenols located in photosynthetic regions of the plant. Flavonoids present in pepper include quercetin, luteolin, myrcetin and capsaicinoids (Hasler, 1998). Flavonoids have been reported to have an influence on colour composition in flowering plants (Koes *et al.*, 2005). These bioactive compounds when consumed have positive effects on the health of humans as they protect body cells against oxidative damage and thus prevent development of heart related diseases, cancer, diabetes, Parkinson's and Alzheimer's disease (Blanco-Rios *et al.*, 2013). In *Capsicum* spp., flavonoid content has been reported to be influenced by the degree of ripeness of the fruits (Perucka and Materska, 2001).

Major food reserves stored in the endosperm of most seeds are proteins, carbohydrates and lipids accumulated towards the end of formation of seeds (Bewley, 1997; Sunda and Giorgini 2000; Lima *et al.*, 2008). These reserves serve as energy source for growth in several plant species until the young seedlings are able to photosynthesize (Pritchard *et al.*, 2002). Each category of storage reserve perform various functions in plants. Schlüter and Crawford (2001) reported that the level of available carbohydrate reserves in plant roots play a major role in plants' ability tolerate anoxia in flood conditions. As a major food reserve, lipids function as source of fuel for germination and seedling development (Nara *et al.*, 2011).

2.9 Effects of Harvesting Stages on Seed Quality

Generally the seed yield and quality parameters in any crop are associated with stage at which the seed crop is harvested (Vasudevan *et al.,* 2008). In early harvested seed crop, the seed quality will be very poor due to more number of immature and undeveloped seeds, while in delayed harvesting, seed quality are affected on account of field weathering (Vasudevan *et al.,* 2008). Hence harvesting of the seed crop at physiological maturity is better as seeds will be having maximum dry weight, higher viability and vigor, besides higher seed yield and yield attributing parameters (Vasudevan *et al.,* 2008).

Demir *et al.*, (2008) also indicated that paramount among the factors that have an influence on the quality of seed is the stage of maturity at harvest. One of the major effects of harvesting too early is low yield and quality, because essential structures of seeds may not have been fully developed. (Keller and Kollmann, 1999; Wang *et al.*, 2008). Adverse environmental conditions such as rainfall or precipitation may also result in sprouting of seeds on mother plants (Ellis and Pieta Filho, 1992; Wang *et al.*, 2008). Physiological maturity is dependent on genotype and is influenced by the environment (Mahesha *et al.*, 2001). It is at this point of plant phenology that seeds attain the highest viability and vigor. Conditions in the environment during seed development and maturity including temperature, availability or absence of water, unavailability of nutrients, disease infection, and effect of pest activity all have an influence on seed quality (Delouche, 1980).

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study comprised field and laboratory experiments. The field experiment was carried out between November 2016 and March 2017 while the nursery and laboratory experiments were set up between April and May 2017.

3.1 Location of Field and Laboratory Experiments

The field and nursery experiments were conducted on the research farm of the Crop science Department of the University of Ghana, Legon in the Coastal savannah zone of Ghana which is about 12km northeast of the centre of Accra. The rainfall pattern is bi-modal with an annual rainfall between 800 mm – 1200 mm and a temperature ranging from 25^0C and 37^0C (Nkansah *et al.,* 2011). The soil type on the farm is classified as the Adenta series which is a savannah Acrisol (FAO/UNESCO, 1986). According to USDA classification, the soil which occurs on the middle slope (gentle to medium (2%-3%)) of Legon hill is moderately well-drained with a depth of 150 cm. The soil profile consist of about 23 cm dark brown to reddish brown sandy clay loam topsoil slightly sticky with a weak, fine granular structure having few to common fine, medium root distribution. Below this is about 17 cm thick yellowish red sandy clay containing few fine roots and few fine quartz and ironstone concretions (Brammer, 1967). The area is in the Coastal Savanna zone with a mean annual rainfall between 750-1000 mm.

The germination test was conducted at the National Seed Testing Laboratory of the Ghana Seed Inspection Division, Plant Protection and Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture, Pokuase located between latitude 5^0, 700’N and longitude 0^0, 302'W. The laboratory analyses was carried out at Department of Plant and Environmental Biology, College of Basic and Applied Sciences of University of Ghana, Accra.

3.2 Genotypes Used for The Experiment

Five (5) genotypes obtained from RMG Ghana limited, Department of Crop science of the College of Basic and Applied Sciences, University of Ghana – Legon and farmers field at Atomic- Accra, which is about 7km from the University farm, were used for the experiment. The genotypes and their sources are indicated Table 1

Table 1: List of genotypes and their sources

Genotype	Source
Shito Adope	RMG Ghana limited
Bird Beak	RMG Ghana limited
Red Scotch Bonnet	RMG Ghana limited
Legon 18	University of Ghana Crop Science department
Ojemma	Farmers' field, Atomic - Accra

3.3 Experiment 1

3.3.1 Raising Seedlings in Nursery

Seeds of the five genotypes (Shito Adope, Bird Beak, Red Scotch Bonnet and Ojemma) were raised in plastic seed trays at the Crop Science research field. The seed trays were filled with top soil which had been sieved to remove debris and stones to obtain fine tilth. The trays were watered after they had been filled with soil and the seeds sown thereafter. For each genotype, four hundred seeds were sown (three-four seeds per hill, thinned to one after emergence) in five seed trays, each tray capable of holding twenty-eight seeds. After sowing, the trays were watered and covered with nylon netting. In all, twenty-five trays were used to raise the seedlings at the nursery. Watering was done once daily throughout the five week nursery period. The nylon mulch was removed eight days after sowing when some seedlings had started to emerge. A starter solution of NPK 15-15-15 at 20 g/l was applied 14 days after sowing. The fungicide Top star 400 SC (A.I. Oxadiargyl) was sprayed at the rate of 10 ml/L every two weeks to control fungal diseases, especially damping-off. Seedlings were transplanted five weeks after sowing (5WAS).

3.3.2 Main Field Preparation, Layout and Transplanting

The main field for raising the parent plants was ploughed and harrowed to loosen the soil. Lining and pegging was then done to demarcate the plots. The field was laid out in a Randomized Complete Block Design with five treatments (the five pepper genotypes) replicated four times. At a spacing of 60 cm x 60 cm, there were 20 plots in total, each plot size was 3 m x 2.4 m with a 1 m space between plots.

Transplanting was done five weeks after sowing onto the main field. There were 30 plants per plot for each genotype per replication giving a total plant population of six hundred. General agronomic practices were carried out till harvesting. These included application of NPK 15-15-15 at a rate of 20 g per plant 14 days after transplanting. Two weeks after top dressing with sulphate of ammonia at a rate of 20 g per plant was applied. The application of NPK and Sulphate of ammonia continued alternately at weekly intervals. Weeds were controlled by hoeing as and when necessary. Disease and pest control on the field were done with Mancozeb 80 WP (Mancozeb dicarbonate) at a rate of 20 g per litre of water to control fungal infection and Decis Forte EC (Deltamethrine) at a rate of 100 g/l to control insect pests. Twenty fruits of each variety at matured green stage were randomly picked from the plants in the middle row 3 weeks after fifty percent fruit set. The matured green fruits harvested were after ripened to full/ red ripe stage. Full/ Red ripe fruits were then picked from the field and seeds extracted from both sets (green mature fruits after ripened to full ripe and full ripe fruits harvested directly from the field) at the same time, and seeds were extracted from different classes of fruits.

3.3.3 Data Collected

Mean plant height: This was determined as the mean perpendicular height (cm) of twelve record plants measured from the soil level to the tip of the shoot at 50 % flowering using a meter rule.

Mean stem girth (SG): This was determined as the mean diameter (mm) of twelve record plants measured at about 10 cm from the base of the plant using Vernier caliper at reproductive stage (50% flowering).

Mean number of primary branches per plant : The number of primary branches of twelve record plants was counted at the 50% flowering stage and the mean number of branches per plant determined.

Mean number of days to 50% flowering: This was determined by counting the number of days from transplanting until 50% of the record plants per genotype had flowered.

Mean number of days to 50% fruiting: This was determined by counting the number of days from transplanting till 50% of each genotype had flowered.

Mean seed number per fruit: Ten fruits were selected at random for each genotype and the seeds extracted and counted. For each genotype, the number of seeds per fruit was determined as the average of the seeds that were counted.

1000 seed weight: One hundred seeds of each genotype were counted and weighed on an electronic balance. The weight obtained was then multiplied by 10 to get 1000 seed weight.

3.3.4 Seed Extraction

Fruits from each maturity class were crushed in with a pestle and soaked in water in a non-metallic container for 72 hours after which the seeds were separated from the pulp, rinsed with tap water and then sun-dried for 3 days.

3.4 Experiment 2

3.4.1 Germination and Early Seedling Performance Test

The germination test was conducted at the National seed testing laboratory of the Plant Protection and Regulatory Services Directorate, Ministry of Food and Agriculture- Pokuase, Accra. The Jacobsen germination table was used for the test. Four hundred seeds extracted from each fruit maturity class were plated on blotter papers and arranged in four replications of 100 in a Completely Randomized Design (ISTA, 2007). Due to the size of the substrate and in order not to overcrowd the seeds, the replicates were broken down into smaller replicates of 25 seeds each. The seeds were dipped in 1% Sodium hypochlorite solution for three minutes before they were plated on the blotter papers that had been moistened with distilled water and placed on plastic strips suspended about 5-7 cm above a bath containing water. Paper wicks were put between the substrate (blotter paper) and passed through slots into the water below through which the seeds obtain moisture. To maintain high humidity around the seeds, an inverted plastic funnel with a hole in the conical end was placed over each blotter paper. Temperature of 24^0C ± 2^0C was maintained in the germination chamber with 12 hours alternating light and darkness.

The treatments are as follows

- Seeds from green mature fruits of Shito Adope after ripened to full ripe
- Seeds from green mature fruits of Bird beak after ripened to full ripe
- Seeds from green mature fruits of Legon 18 after ripened to full ripe
- Seeds from green mature fruits of Red scotch bonnet after ripened to full ripe
- Seeds from green mature fruits of Ojemma after ripened to full ripe
- Seeds from full ripe fruits of Shito Adope.
- Seeds from full ripe fruits of Bird Beak.
- Seeds from full ripe fruits of Legon 18.
- Seeds from full ripe fruits of Red Scotch Bonnet.
- Seeds from full ripe fruits of Ojemma.

The set-up was monitored daily and germination counts done every other day from day one to day fourteen in accordance with the ISTA guidelines (ISTA, 2007). Percentage germination was calculated using the formula:

$$\text{Germination \%} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds planted}} \times 100$$

The second part of experiment two was carried out in a similar way to experiment one. Seeds extracted from each maturity class were sowed again in seed trays arranged in a Completely Randomized Design replicated four times. Each seed tray had twenty-eight cells. Emergence and seedling growth were monitored weekly and data collected on the growth of the seedlings till transplanting stage (from week three, week four and week five). The following data were taken:

- **Mean shoot length:** This was determined as the mean length (cm) of five plants measured from the soil level to the tip of the shoot randomly picked 3WAS, 4WAS and 5WAS using a meter rule.
- **Mean root length :** This was determined as the mean root length (cm) of five plants measured from the base of the plant to the tip of the longest root 3WAS, 4WAS and 5WAS with a meter rule
- **Mean number of leaves:** This was determined as the mean number of leaves of five plants counted at 3WAS, 4WAS and 5WAS.
- **Mean seedling girth:** This was determined as the mean girth (cm) of five plants measured at 2cm from the base of the plant using a Digital caliper

- **Seed vigour:** This was determined as the first seedling count which germinated seven days after sowing (Lima *et al.*, 2003).
- **Total fresh weight:** The total fresh weight was determined by rinsing the soil off roots of the five uprooted sample plants with tap water and then the weight (g) taken with an electronic balance.
- **Total dry weight:** The total dry weight was determined as the weight of the five sample plants after keeping them in an oven at 70° C for 24-48 hours.

3.5 Experiment 3

3.5.1 Nutritional and Phytochemical Analyses

A third experiment was set up in the laboratory at the Department of Plant and Environmental Biology, University of Ghana to ascertain the content of various food storage materials and phytochemicals present in the seeds extracted in experiment 1. The food storage materials and phytochemicals investigated were:

- Proteins: Determination of protein content was by the macrokjedahl procedure (AOAC, 1990). Apparatus used were Kjeldahl digestion and distillation rack and flasks. Two gram (2 g) of pulverized seeds of each genotype was poured on a filter paper which had been prefolded as an envelope. The wrapped sample was then introduced into a kjeldahl flask. A similar piece of paper was used as blank. The following were then added; three to four glass boiling chips, 10 g of chiball, 10 g of Reese and Williams reaction mixture (0.1 g SeO_2 + 0.25 g $CuSO_4$ + 9.65 g K_2SO_4). The resulting mixture was shaken carefully after which 25 ml concentrated H_2SO_4 was added by carefully pouring down the sides of the flask. The flask was then placed on a heater. The reaction was observed until first frothing ceased and then the flask was lifted to eliminate bumping or excessive frothing. Once the digest became clear, digestion was continued for 30 minutes, with rotating the flask 180^0C every 10 minutes. The flask was then allowed to stand for some time to cool. After, the digestion flask was then connected to a receiving erlenmeyer flask by a tube which contained boric acid solution (2%) and a few drops of mixed indicator (0.06 bromocresol green, 0.04 g methyl red in 100 ml ethyl alcohol). Distilled water (100 ml) was added to the digestion flask and shaken to dissolve any precipitate. While holding the flask in a slanting position NaOH solution (50%, 80 ml) was added to neutralize H_2SO_4 with 13 ml excess to ensure alkaline conditions. A pinch of zinc dust was then added and without shaking, attached to a connecting bulb. Afterwards, the flask was shaken gently but thoroughly. The resulting mixture was then distilled until more than 150 ml of distillate was collected into the boric acid. The delivery tube was then disconnected and rinsed with distilled water into the Erlenmeyer flask. The distillate was titrated with 0.1N H_2SO_4 to faint pink end point. Nitrogen content was reported in percentage as follows and percentage protein determined as follows:

$$\%N = \frac{(\text{Sample titre} - \text{Blank titre})}{(\text{Weight of sample in mg})} \times (\text{Normality of } H_2SO_4 \text{ or HCL} \times 14 \times 100$$

$$\%\text{Protein} = \%N \times 6.25(\text{Conversion factor})$$

- Fats: Fat content was determined by the soxhlet extraction method (AOAC, 1990). The equipment used in determining fat content included Soxhlet extraction equipment, steam bath and extraction thimbles. About 2 g of the pulverized pepper seeds was weighed directly into an extraction thimble and plugged with free fat cotton wool. The thimble was placed in an extraction tube by allowing it to slide down the side of the tube. A clean dried soxhlet flask with fat-free boiling chips was weighed and filled with petroleum ether (BP 40-60^{0}C) to a little over half of its volume. An extractor was then assembled on a rack, the heater and condenser water were turned on to check for water leaks before refluxing rapidly for about 3 hours after which the extractor was disconnected. The thimble was lifted up to the top of the tube with tongs and clips to the side for draining. Thimble was then removed and distillation continued using a siphon to reclaim the ether. To remove any remaining ether, the flask was placed in a steam bath to allow the final few millilitres of ether to evaporate. The flask was then dried in an oven at 60^{0}C overnight, cooled in a desiccator and weighed. Percentage crude fat was reported on ‘as is’ basis

- Carbohydrates: Carbohydrate content was determined by difference method where the other constituents in the sample (protein, fat, water, ash) were determined individually, summed up and subtracted from the total weight of the sample.
- Total phenolic content: This was determined by extracting 0.5g of pulverized sample of each seed class in 20 ml of methanol. An amount of this extract (2 ml) was diluted with 20 ml of distilled water. After, 20 µl of diluted sample was pipetted into a cuvette and then 1.58 ml and 100 µl of distilled water and Folin-Ciocalteau respectively was added. The mixture was shaken to mix and then Sodium carbonate (Na_2CO_3) added after 5 minutes. The resulting solution was placed in an oven at 40ºC for 30 minutes. Absorbance was then determined by the spectrophotometer at 765nm against the blank (methanol) after 90 minutes. The concentration of the total phenolic compounds was then calculated using the

standard curve of gallic acid (0.2 – 1.0 mg/ml) with the equation y= 0.624x – 0.939 and results expressed as mg of gallic acid equivalent (GAE/mg) per 100 ml of extract.

- Total flavonoids: The total flavonoid content in the pepper seed samples was determined by the modified aluminium chloride calorimetric procedure (Barros *et al.,* 2007). Extracts of the sample (100 µl, 100 mg/ml) was added to 500 µl of distilled water and 20 µl sodium nitrite, $NaNO_2$ (5%, 30 µl). A solution of aluminium chloride $AlCl_3$ was added to the mixture after 5 minutes. After allowing the mixture to stand for about 6 minutes, sodium hydroxide (1 M, 200 µl) and distilled water (110 µl) were pipetted into the solution and then shaken. Absorbance of solution was measured at various wave lengths (SpectraMax plus 384, United States). The standard curves for the various flavonoid compounds was used to determine the concentrations of the flavonoids present and expressed as mg/ml of the extract.

Table 2: Flavanoid compounds and their standard curves

Flavonoid compound	Wavelength (nm)	Standard curves
Rutin (mg/100ml)	425	Y = 0.010x + 0.223
Quercetin (mg/100ml)	415	Y = 0.015x + 0.246
Kaemferrol (mg/100ml)	368	Y = 0.028x + 0.435

3.5.2 Statistical Analysis of Data

All data collected on vegetative and reproductive parameters, germination and early seedling performance as well as nutritional and phytochemical composition were subjected to analysis using Analysis of Variance and differences among means separated by least significant difference (LSD) at 5% level of significance for interpretation of the results (Steel and Torie, 1980). The Genstat computer package version 12 was used for the analysis.

3.6 Estimation Correlation Coefficient

The Pearson's correlation coefficient was used to determine the link between the phytochemicals present in the seeds and germination of the pepper genotypes.

CHAPTER FOUR

4.0 RESULTS

4.1 Performance Of Genotypes Of Pepper For Agro-Morphological Traits

4.1.1 Mean plant height (cm) (PHT)

Mean plant height values for the five pepper genotypes taken at flowering are presented in Table 4. The genotype Ojemma recorded the lowest plant height of 23.73 cm, followed by Shito Adope, Legon 18 and Bird Beak. The genotype Red Scotch Bonnet recorded the highest height of 32.53 cm and a grand mean of 28.48 cm. From Analysis of Variance, significant differences ($P < 0.01$) were observed among the genotypes in terms of their plant height at flowering.

4.1.2 Mean stem girth (cm) (SG)

The mean values for stem girth taken at flowering are shown in Table 4. The lowest mean value of 2.71 cm was observed in Bird Beak while the genotype Shito Adope had the highest mean value of 3.20 cm and a grand mean of 2.95 cm. From Analysis of variance, there were no significant differences in the pepper genotypes.

4.1.3 Mean Number of leaves per plant (NLP)

Highly significant differences ($P < 0.001$) were shown in leaf numbers among the genotypes. The lowest mean value of 24 was observed in Red Scotch Bonnet plants while the highest mean value of 49 was observed in Shito Adope plants about a grand mean of 36 (Table 4).

4.1.4 Mean number of Branches per plant (NBP)

Mean values for number of branches per plant in the genotypes of pepper are presented in Table 3. The lowest number of 4 was observed in the genotype Red Scotch Bonnet while Shito Adope had the greatest mean number of 9 about a grand mean of 6. There were significant differences ($P< 0.01$) among the genotypes.

Table 3: Mean values for plant height, stem girth, number of leaves and number of branches of the pepper genotypes

Genotype	**Mean plant height (cm)**	**Mean stem girth (mm)**	**Mean no. of leaves**	**Mean no. of branches**
Bird Beak	31.12	2.71	34	8
Legon 18	28.93	2.74	47	7
Ojemma	23.73	3.15	26	5
Red Scotch Bonnet	32.53	2.9	24	4
Shito Adope	26.02	3.2	49	9
Grand mean	24.48	2.95	36	6
$LSD_{(0.05)}$	4.55	0.59	4.7	2.55

4.2 Reproductive traits performance of five genotypes

4.2.1 Mean Days to 50% flowering

Mean values for number of days to 50% flowering are presented in Table 4. From Analysis of variance, the genotypes differed significantly (P<0.01) in the mean days to flowering. The highest mean value of 56 days was observed in the genotype Ojemma while the lowest mean value of 35 days was recorded in the genotype Shito Adope.

4.2.2 Mean Days to 50% fruiting

Mean values for number of days to 50% fruiting are presented in Table 4. The highest mean value of 108 days was seen in the genotype Ojemma while the genotype Shito Adope had the lowest mean value of 58 days. From Analysis of variance, very high significant differences (P<0.01) were observed among the genotypes in the days to fruiting.

Table 4: Mean number of days to 50 % flowering and fruiting of the 5 pepper genotypes

Genotype	**Days to 50% flowering)**	**Days to 50% fruiting**
Bird Beak	38	64
Legon 18	43	78
Ojemma	56	108
Red Scotch Bonnet	52	96
Shito Adope	35	58
Grand mean	47	81
LSD$_{(0.05)}$	4.259	15.29

4.3 Seed Quality Traits

4.3.1 Mean Seed Number Per Fruit

The mean values for number of seeds per fruit for the 5 pepper genotypes are presented in Table 5. At the full ripe stage, the highest seed numbers per fruit of 74 was observed in the genotype Bird Beak while Red Scotch Bonnet had the least seed numbers per fruit of 29 about a grand mean of 48. For seeds extracted from physiologically mature fruits that had gone through after ripening, the highest mean value of 44 was recorded in the genotype Bird Beak while the lowest value of 20 was recorded in the genotype Red Scotch Bonnet about a grand mean of 33. For the combined analyses, the highest mean value of 59 was recorded in the genotype Bird Beak and the lowest of

24 recorded in Red Scotch Bonnet. Very high significant differences (P<0.001) were shown in the genotypes, harvesting stage and genotype x harvesting stage interaction (Appendix 7).

Table 5: Effect of genotype and harvesting stage on seed number per fruit of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	74	44	59
Legon 18	42	33	37
Ojemma	42	29	36
Red Scotch Bonnet	29	20	24
Shito Adope	54	39	46
Harvesting stage Mean	48	33	40.4

CV (%) 12.6

Lsd (0.05) Genotype= 5.22 **Harvesting stage**= 3.30 **Harvesting stage x genotype**= 7.38

4.3.2 Mean 1000 Seed Weight of The Genotypes Of Pepper

Mean 1000 seed weight values are presented in Table 6. For seeds extracted from full ripe fruits, the genotype Shito Adope had the heaviest seeds with a mean value of 5.04 g while the genotype Ojemma with a value of 2.78 g had the lightest seeds. At the physiological maturity stage, the highest mean seed weight was observed in Shito Adope with a value of 4.0 g while the lowest mean value of 1.4 g was observed in Legon 18. For the combined analysis the genotype Shito

Adope had the highest mean of 4.51 g while the lowest mean weight of 2.12 g was observed in the genotype Ojemma. From the combined analysis of variance very highly significant (P<0.001) differences in the genotypes, harvesting stages and genotype x harvesting stage interaction was observed (Appendix 8).

Table 6: Effect of genotype and harvesting stage on mean seed weight (g) of the 5 pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	4.29	3.10	3.70
Legon 18	4.04	1.40	2.72
Ojemma	2.78	1.46	2.12
Red Scotch Bonnet	4.6	2.47	3.53
Shito Adope	5.04	3.98	4.51
Harvesting stage mean	4.15	2.48	3.32

CV (%) 8.6

Lsd $_{(0.05)}$ **Genotype=** 0.29 **Harvesting stage=** 0.18 **Harvesting stage x genotype=** 0.41

4.4 Germination Performance of Pepper Genotype Seeds Harvested at Different Maturity Stages

4.4.1 Mean Germination Percentage

Mean germination percentage values of the seeds of the five genotypes at different maturity stages are presented in Table 7. At the full ripe stage, seeds of the genotype Shito Adope had the highest percentage germination of 88.5% while the genotype Red scotch had the lowest mean percentage of 13%. For seeds harvested from physiologically mature fruits that had been after ripened to full ripe, the highest mean percentage value of 68% was observed in the genotype Shito Adope while Red Scotch Bonnet also had the lowest mean value of 3.75%. The genotype Shito Adope had the highest mean percentage of 78.25% for the combined analysis while the lowest value of 8.38% was seen in the genotype Red Scotch Bonnet. From the combined analysis of variance highly significant differences ($P<0.001$) was observed in genotypes, harvesting stages and genotype x harvesting stages interaction (Appendix 9).

Table 7: Effect of genotype and harvesting stage on germination (%) of the 5 pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	83.50	46	64.75
Legon 18	68.50	28.75	48.62
Ojemma	47.25	23.50	35.38
Red Scotch Bonnet	13.00	3.75	8.38
Shito Adope	88.50	68.00	78.25
Harvesting stage mean	60.15	34	47.08

CV (%) 9.2

Lsd $_{(0.05)}$ Genotype= 4.44 **Harvesting stage**= 2.81 **Harvesting stage x genotype**= 6.29

4.4.2 Percentage Seed Vigour

The mean for seed vigour in the pepper genotypes is presented in Table 8. At the full ripe/ mature stage, seeds of the genotype Bird Beak had the highest vigour with a mean number of 79 seeds out of 100 germinating at the first count while the genotype Red Scotch Bonnet had the least mean number of 7 seeds out of 100 germinating at the first count. For seeds extracted from physiologically mature fruits that had been after ripened to full ripe, the genotype Shito Adope was the most vigorous with a mean number of 61 seeds out of 100 seeds germinating at the first count while the genotype Red Scotch Bonnet was the least vigorous with a mean number of 2 seeds out of 100 germinating at the first count. For the combined analysis the genotype Shito Adope had 69 seeds out of 100 germinating at the first count which was the highest while the genotype Red scotch had the lowest mean of 4 seeds germinating after the first count. From the combined analysis of variance very high significant differences was observed in genotype, harvesting stage and genotype x harvesting stage interaction (Appendix 10).

Table 8: Effect of genotype and harvesting stage on seed vigour (%) of the 5 pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	78.50	41	59.75
Legon 18	42	24.50	33.25
Ojemma	32.25	16.25	24.25
Red Scotch Bonnet	6.75	1.50	4.12
Shito Adope	77.75	60.50	69.12
Harvesting stage mean	47.45	28.75	38.10

CV (%) 11.10

Lsd $_{(0.05)}$ Genotype= 4.32 Harvesting stage= 2.73 Harvesting stage x genotype= 6.11

4.5 Early Seedling Growth Performance

4.5.1 Mean Percentage Emergence of Seeds of the Pepper Genotypes Harvested at Different Maturity Stages

Mean percentage emergence values of the seeds of the five genotypes at different maturity stages are presented in Table 9. For seeds extracted from fruits at the full ripe stage, the genotype Bird Beak had the highest percentage emergence of 92% while the genotype Red Scotch Bonnet had the lowest mean percentage of 25%. For seeds extracted from physiologically mature fruits that had been after ripened to full ripe, the highest mean percentage value of 85.7% was observed in the genotype Shito Adope while Red Scotch Bonnet again had the lowest mean value of 9.8%. The genotype Shito Adope had the highest mean percentage of 86.6% for the combined analysis while the genotype Red Scotch Bonnet recorded the lowest value of 17.4%. From the combined analysis of variance highly significant differences (P<0.001) was observed in genotypes, harvesting stages and genotype x harvesting stages interaction (Appendix 11).

Table 9: Effect of genotype and harvesting stage on seedling emergence (%) of the 5 pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird beak	92	74.1	83
Legon 18	85.7	45.5	65.6
Ojemma	85.7	31.2	58.5
Red scotch	25	9.8	17.4
Shito Adope	87.5	85.7	86.6
Harvesting stage mean	75.2	49.3	62.2

CV (%) 11.9

Lsd $_{(0.05)}$ Genotype= 7.56 **Harvesting stage= 4.78** **Harvesting stage x genotype= 10.68**

4.5.2 Mean Seedling Shoot Length (cm) 3 Weeks After Sowing

Mean seedling shoot length values 3 WAS are presented in Table 10. For seeds extracted from full ripe fruits, the genotype Legon 18 had the highest shoot length of 5.23 cm while the genotype Red Scotch Bonnet had the lowest mean length of 3.43 cm. Shito Adope had the highest mean length of 4.89 cm while Red Scotch Bonnet had the lowest mean length of 2.25 cm with respect to seeds harvested at physiological maturity and after ripened to full ripe. For the combined analysis the genotype Legon 18 had the highest mean of 4.64 cm while the genotype Red Scotch Bonnet had the lowest value of 2.84 cm. High significant differences (P<0.01) in genotypes as well as harvesting stages was observed but no significant differences in genotype x harvesting stages interaction from the combined analysis of variance (Appendix 12).

Table 10: Effect of genotype and harvesting stage on seedling shoot length (cm) of the pepper genotypes 3WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird beak	4.96	4.25	4.61
Legon 18	5.23	4.05	4.64
Ojemma	3.79	2.91	3.35
Red scotch	3.43	2.25	2.84
Shito Adope	4.34	4.89	4.61
Harvesting stage mean	4.35	3.67	4.01

CV (%) 21.1

Lsd $_{(0.05)}$ Genotype= 0.87 **Harvesting stage= 0.55** **Harvesting stage x genotype= 1.22**

4.5.3 Mean Seedling Root Length 3 Weeks After Sowing

Values of mean root length 3WAS are presented in Table 11. Significant differences (P<0.001) occurred among genotypes. Legon 18 had the highest mean root length of 10.14 cm while Red

Scotch Bonnet had the lowest mean length of 4.71 cm for seeds harvested from full ripe fruits. For seeds harvested at the physiologically mature stage and after ripened to full ripe, genotype Shito Adope had the highest mean length of 10.08 cm while genotype Red Scotch Bonnet had the lowest mean root length of 4.64 cm. The genotype Shito Adope had the highest mean root length of 9.33 cm for the combined analysis while genotype Red Scotch Bonnet had the lowest mean length of 4.67 cm. From the combined analysis of variance highly significant differences (P<0.001) was observed among genotypes but no significant differences (P>0.05) in harvesting stages and genotype x harvesting stages interaction (Appendix 13).

Table 11: Effect of genotype and harvesting seedling root length (cm) of the 5 pepper genotypes 3WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	8.13	9.10	8.62
Legon 18	10.14	7.71	8.93
Ojemma	8.51	6.27	7.39
Red Scotch Bonnet	4.71	4.64	4.67
Shito Adope	8.58	10.08	9.33
Harvesting stage mean	8.01	4.19	7.79

CV (%) 27.5

Lsd $_{(0.05)}$ Genotype= 2.19 Harvesting stage= 1.38 Harvesting stage x genotype= 3.09

4.5.4 Mean Stem Girth (mm) 3 Weeks After Sowing

Mean values for stem girth 3WAS are presented in Table 12. The genotype Legon 18 had the highest mean girth of 1.20 mm while Red Scotch Bonnet had the lowest girth of 0.60 mm for seeds harvested from full ripe fruits. For seeds harvested at the physiologically mature stage and after ripened to full ripe, the genotype Shito Adope had the highest mean girth of 1.25 mm while the genotype Red Scotch Bonnet had the lowest mean girth of 0.61 mm. For the combined analysis genotype Shito Adope had the highest mean girth of 1.16 mm while the genotype Red Scotch Bonnet recorded the lowest girth of 0.48 mm. From the combined analysis of variance, highly significant differences (P<0.001) was observed in genotypes but no significant differences (P<0.05) in harvesting stages and genotype x harvesting stages interaction (Appendix 14).

Table 12: Effect of genotype and harvesting stage on stem girth (mm) of the 5 pepper genotypes 3WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	1.15	1.13	1.14
Legon 18	1.20	1.05	1.12
Ojemma	0.99	0.61	0.80
Red Scotch Bonnet	0.60	0.36	0.48
Shito Adope	1.07	1.25	1.16
Harvesting stage mean	1.00	0.88	0.94

CV (%) 24.4

Lsd $_{(0.05)}$ Genotype= 0.25 **Harvesting stage= 0.16** **Harvesting stage x genotype= 0.36**

4.5.5 Mean Shoot Length 4 Weeks After Sowing

Mean seedling shoot length values 4WAS are presented in Table 13. For seeds extracted from full ripe fruits, the genotype Legon 18 had the highest mean shoot length of 7.23 cm while the genotype Red Scotch Bonnet had the lowest mean shoot length of 4.59 cm. Bird Beak had the highest mean length of 6.42 cm while Red Scotch Bonnet had the lowest mean length of 2.25 cm with respect to seeds harvested at physiological maturity and after ripened to full ripe. For the combined analysis the genotype Legon 18 had the highest mean of 6.63 cm while the genotype Red Scotch Bonnet had the lowest value of 3.42cm. From the combined analysis of variance highly significant differences (P<0.01) was observed in genotypes and harvesting stages but no significant differences (P>0.05) in genotype x harvesting stages interaction (Appendix 15).

Table 13: Effect of genotype and harvesting stage on seedling shoot length (cm) of the pepper genotypes 4WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	6.39	6.42	6.41
Legon 18	7.23	6.03	6.63
Ojemma	4.89	2.66	3.78
Red Scotch Bonnet	4.59	2.25	3.42
Shito Adope	5.62	5.91	5.77
Harvesting stage mean	5.74	4.66	5.20

CV (%) 29.1

Lsd $_{(0.05)}$ Genotype= 1.54 Harvesting stage= 0.98 Harvesting stage x genotype= 2.18

4.5.6 Mean Seedling Root Length 4 Weeks After Sowing

Values of mean root length 4WAS are presented in Table 14. Legon 18 had the highest mean root length of 11.69 cm while Red Scotch Bonnet had the lowest mean length of 6.52cm for seeds harvested from full ripe fruits. For seeds harvested at the physiologically mature stage and after ripened to full ripe, the genotype Legon 18 had the highest mean root length 11.66 cm of while the genotype Red Scotch Bonnet had the lowest mean root length of 1.9 cm. The genotype Legon 18 had the highest mean root length of 11.68 cm for the combined analysis while the genotype Red Scotch had the lowest root length of 4.21 cm. From the combined analysis of variance high significant differences ($P<0.01$) was seen in genotypes but no significant differences ($P>0.05$) in harvesting stages and genotype x harvesting stages interaction (Appendix 16).

Table 14: Effect of genotype and harvesting stage on seedling root length (cm) of the pepper genotypes 4WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	9.84	11.29	10.56
Legon 18	11.69	11.66	11.68
Ojemma	8.68	5.90	7.29
Red Scotch Bonnet	6.52	1.90	4.21
Shito Adope	10.32	10.59	10.46
Harvesting stage mean	9.41	8.27	8.84

CV (%) 45.2

Lsd $_{(0.05)}$ Genotype= 4.08 Harvesting stage= 2.58 Harvesting stage x genotype= 5.77

4.5.7 Mean Stem Girth (mm) 4 Weeks After Sowing

Mean values for stem girth 4WAS are presented in Table 15. The genotype Legon 18 had the highest mean girth of 1.63 mm while Red Scotch Bonnet had the lowest mean girth of 1.15 mm for seeds harvested from full ripe fruits. For seeds harvested at the physiologically mature stage and after ripened to full ripe, the genotype Shito Adope had the highest mean girth of 1.56 mm while the genotype Red Scotch Bonnet had the lowest mean girth of 0.52 mm. For the combined analysis genotype Legon 18 had the highest mean girth of 1.59 mm while the genotype Red Scotch Bonnet recorded the lowest mean girth of 0.84mm. From the combined analysis of variance high significant differences ($P<0.05$) was observed in genotypes and harvesting stages but no significant differences ($P>0.05$) in genotype x harvesting stages interaction (Appendix 17).

Table 15: Effect of genotype and harvesting stage on seedling stem girth (mm) of the pepper genotypes 4WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	1.43	1.51	1.49
Legon 18	1.63	1.54	1.59
Ojemma	1.32	0.83	1.07
Red Scotch Bonnet	1.15	0.52	0.84
Shito Adope	1.60	1.56	1.58
Harvesting stage mean	1.43	1.19	1.31

CV (%) 26.8

Lsd $_{(0.05)}$ Genotype= 0.36 Harvesting stage= 0.23 Harvesting stage x genotype= 0.51

4.5.8 Mean Seedling Shoot Length (cm) 5 Weeks After Sowing

Mean seedling shoot length values recorded 5WAS are presented in Table 16. For seeds extracted from full ripe fruits, the genotype Legon 18 had the highest shoot length of 7.21 cm while the genotype Red Scotch Bonnet had the lowest mean length of 4.59 cm. Bird Beak had the highest mean length of 7.59 cm while Red Scotch Bonnet had the lowest mean length of 0cm with respect to seeds harvested at physiological maturity and after ripened to full ripe. For the combined analysis the genotype Bird Beak had the highest mean of 7.33 cm while the genotype Red Scotch Bonnet recorded the lowest value of 1.63 cm. From the combined analysis of variance high significant differences ($P<0.01$) was observed in genotypes and harvesting stages but no significant differences ($P>0.05$) in genotype x harvesting stages interaction (Appendix 18).

Table 16: Effect of genotype and harvesting stage on seedling shoot length (cm) of the pepper genotypes 5WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	7.07	7.59	7.33
Legon 18	7.21	6.21	6.71
Ojemma	5.34	3.39	4.37
Red Scotch Bonnet	3.26	0.00	1.63
Shito Adope	6.43	6.84	6.63
Harvesting stage mean	5.86	4.80	5.33

CV (%) 30.3

Lsd $_{(0.05)}$ Genotype= 1.65 Harvesting stage= 1.04 Harvesting stage x genotype= 2.33

4.5.9 Mean Seedling Root Length (cm) 5 Weeks After Sowing

Values of mean root length 4WAS are presented in Table 17. Legon 18 had the highest mean root length of 13.6 cm while Red Scotch Bonnet hadd the lowest mean root length of 4.86 cm for seeds harvested from full ripe fruits. For seeds harvested at physiological maturity and after ripened to full ripe, the genotype Legon 18 had the highest mean root length of 14.13 cm while the genotype Red Scotch Bonnet had the lowest mean root length of 1.9 cm. The genotype Legon 18 had the highest mean root length of 11.68 cm for the combined analysis while the genotype Red Scotch Bonnet had no value as plants for analysis had been exhausted due to poor plant emergence. From the combined analysis of variance highly significant differences (P<0.01) was observed among genotypes but no significant differences (P>0.05) in harvesting stages and genotype x harvesting stages interaction (Appendix 19).

Table 17: Effect of genotype and harvesting stage on seedling root length (cm) of the pepper genotypes 5WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	12.43	13.61	13.02
Legon 18	13.60	14.13	13.86
Ojemma	13.41	11.36	12.39
Red Scotch Bonnet	4.86	0.00	2.43
Shito Adope	12.98	13.59	13.29
Harvesting stage mean	11.46	10.54	11.00

CV (%) 36

Lsd $_{(0.05)}$ Genotype= 4.04 **Harvesting stage= 2.56** **Harvesting stage x genotype= 5.71**

4.5.10 Mean Seedling Stem Girth (mm) 5 Weeks After Sowing

Mean values for stem girth 5WAS are presented in Table 18. The genotype Legon 18 had the highest mean girth of 1.92 mm while Red Scotch Bonnet had the lowest mean girth of 1.06 mm for seeds harvested from full ripe fruits. For seeds harvested at the physiologically mature stage and after ripened to full ripe, genotype Bird Beak had the highest mean girth of 2.13 mm while the genotype Red Scotch Bonnet had no value as plants for analysis had been exhausted due to poor plant emergence. For the combined analysis genotype Bird Beak had the highest mean girth of 1.93 mm while the genotype Red Scotch Bonnet had the lowest mean girth of 0.53 mm. From the combined analysis of variance significant differences ($P<0.05$) was observed in genotypes and genotype x harvesting stages interaction but no significant differences ($P>0.05$) in harvesting stages (Appendix 20).

Table 18: Effect of genotype and harvesting stage on seedling girth (mm) in the pepper genotypes 5WAS

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	1.73	2.13	1.93
Legon 18	1.92	1.89	1.90
Ojemma	1.67	1.28	1.47
Red Scotch Bonnet	1.06	0.00	0.53
Shito Adope	1.84	1.91	1.87
Harvesting stage mean	1.64	1.44	1.54

CV (%) 26.4

Lsd $_{(0.05)}$ Genotype= 0.42 **Harvesting stage= 0.26** **Harvesting stage x genotype= 0.59**

4.6 Polyphenols and Food Storage Compounds Content of Pepper Genotypes

4.6.1 Mean Rutin Content in Seeds of Pepper Genotypes (mg /100 ml)

The mean content of rutin in seeds of the pepper genotypes are shown in Table 19. The genotype Red Scotch Bonnet had the highest mean rutin content of 9.27 mg/100 ml which was significantly different from the genotype Bird Beak which had a mean content of 0.23 mg/100 ml for seeds extracted from fully ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Ojemma had a significantly highest mean rutin content of 10.97 mg/100 ml while Red Scotch Bonnet had the lowest mean content of 0.23 mg/100 ml. The interaction effect was statistically highly significant ($P<0.001$) with Ojemma having the highest mean concentration of 9.1 mg/100ml and Shito Adope having the lowest mean concentration of 2.92 mg/100 ml (Appendix 21).

Table 19: Effect of genotype and harvesting stage on rutin content (mg/100ml) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	0.23	7.27	3.75
Legon 18	5.03	8.43	6.73
Ojemma	7.23	10.97	9.10
Red Scotch Bonnet	9.27	0.23	4.75
Shito Adope	2.00	3.83	2.92
Harvesting stage mean	4.75	6.15	5.45

CV (%) 3.5

Lsd $_{(0.05)}$ Genotype= 0.23 Harvesting stage= 0.15 Harvesting stage x genotype= 0.32

4.6.2 Mean Quercetin Content in Seeds of Pepper Genotypes (mg/100ml)

The mean content of quercetin in seeds of the pepper genotypes are shown in Table 20. The genotype Ojemma had the highest mean quercetin content of 9.27 mg/100ml which was significantly different from the genotype Bird Beak which had the lowest mean content of 0.11 mg/100ml for seeds extracted from fully ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Ojemma had significantly highest mean quercetin content of 4.36 mg/100ml while Red Scotch Bonnet had the lowest mean content of 0.17 mg/100ml. The interaction effect was statistically highly significant (P<0.001) with Ojemma having the highest mean concentration of 4.36 mg/100ml and Shito Adope obtaining the lowest mean concentration of 0.32 mg/100ml (Appendix 22).

Table 20: Effect of genotype and harvesting stage on quercetin content (mg/100ml) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	0.11	2.70	1.41
Legon 18	0.56	3.36	1.96
Ojemma	4.36	4.36	4.36
Red Scotch Bonnet	3.24	0.16	1.70
Shito Adope	0.24	0.40	0.32
Harvesting stage mean	1.70	2.20	1.95

CV (%) 36

Lsd $_{(0.05)}$ Genotype= 4.04 **Harvesting stage= 2.56** **Harvesting stage x genotype= 5.71**

4.6.3 Mean Kaemferrol Content in Seeds of Pepper Genotypes (mg/100ml)

The mean kaemferrol content in seeds of the pepper genotypes are shown in Table 21. The genotype Red Scotch Bonnet had the highest mean kaemferrol content of 14.31 mg/100ml which was significantly different from the genotype Bird Beak which had the lowest mean content of 6.31 mg/100ml for seeds extracted from full ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Ojemma had significantly highest kaemferrol content of 14.80 mg/100ml while Red Scotch Bonnet had the lowest content of 8.37 mg/100ml. The interaction effect was statistically highly significant ($P<0.001$) with Ojemma having the highest mean concentration of 14.55 mg/100ml and Shito Adope having the lowest mean concentration of 7.34 mg/100ml (Appendix 23).

Table 21: Effect of genotype and harvesting stage on kaemerrol content (mg/100ml) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird beak	8.67	14.64	11.66
Legon 18	10.58	9.5	10.05
Ojemma	14.31	14.80	14.55
Red Scotch Bonnet	11.85	8.73	10.29
Shito Adope	6.31	8.37	7.34
Harvesting stage mean	10.34	11.21	10.77

CV (%) 0.6

Lsd $_{(0.05)}$ Genotype= 0.07 **Harvesting stage= 0.05** **Harvesting stage x genotype= 0.11**

4.6.4 Mean Total Phenols in Seeds of Pepper Genotypes

The mean total phenol content in seeds of the pepper genotypes are shown in Table 22. The genotype Shito Adope had the highest mean total phenol content of 2.03 GAE/mg/100ml which was significantly different from the genotype Ojemma which had the lowest mean total content of 1.68 GAE/mg/100ml for seeds extracted from full ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Legon 18 had significantly highest mean total phenol content of 2.23 GAE/mg/100ml while Red Scotch Bonnet had the lowest mean content of 1.66 GAE/mg/100ml. The interaction effect was statistically highly significant (P<0.001) with Legon 18 obtaining the highest mean total concentration of 1.98 GAE/mg/100ml and Red Scotch Bonnet having the lowest mean concentration of 1.67 GAE/mg/100ml (Appendix 24).

Table 22: Effect of genotype and harvesting stage on total phenols content (GAE/mg/100ml) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	0.92	0.65	0.79
Legon 18	8.11	7.66	7.88
Ojemma	10.52	7.25	8.89
Red Scotch Bonnet	1.94	1.06	1.50
Shito Adope	5.32	4.34	4.83
Harvesting stage mean	5.36	4.19	4.77

CV (%) 4.4

Lsd $_{(0.05)}$ Genotype= 0.25 Harvesting stage= 0.16 Harvesting stage x genotype= 0.35

4.6.5 Carbohydrate Content

Mean values of carbohydrate content in seeds of the pepper genotypes are shown in Table 23. The genotype Shito Adope had the highest carbohydrate composition of 89.97% of seed dry mass which was significantly different from the genotype Ojemma which had the lowest mean composition of 78.36% of seed dry mass for seeds extracted from full ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Red Scotch Bonnet had the highest carbohydrate composition of 89.11% of seed dry mass while Legon 18 had the lowest value of 69.55%. The interaction effect was statistically highly significant (P<0.001) with Red scotch having the highest mean composition of 88.77% and Red scotch obtaining the lowest mean composition of 75.53% of seed dry mass (Appendix 25).

Table 23: Effect of genotype and harvesting stage on carbohydrate content (%) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	89.63	83.35	86.492
Legon 18	80.92	69.55	75.23
Ojemma	78.36	81.23	79.80
Red Scotch Bonnet	88.43	89.11	88.77
Shito Adope	89.97	86.39	88.18
Harvesting stage mean	85.46	81.93	83.69

CV (%) 0.4

Lsd $_{(0.05)}$ Genotype= 0.42 Harvesting stage= 0.27 Harvesting stage x genotype= 0.60

4.6.6 Protein Content

Mean values of protein content in seeds of the pepper genotypes are shown in Table 24. The genotype Legon 18 had the highest protein composition of 0.80% of seed dry mass which was significantly different from the genotype Shito Adope which had the lowest mean content of 0.46% of seed dry mass for seeds extracted from full ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, Legon 18 again had the highest protein content of 0.70% of seed dry mass while Shito Adope had the lowest value of 0.49%. The interaction effect was statistically highly significant ($P<0.001$) with Legon 18 having the highest mean content of 0.75% and Shito Adope having the lowest mean content of 0.47% of seed dry mass (Appendix 26).

Table 24: Effect of genotype and harvesting stage on protein content (%) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	0.67	0.62	0.64
Legon 18	0.80	0.70	0.75
Ojemma	0.62	0.52	0.57
Red Scotch Bonnet	0.50	0.64	0.57
Shito Adope	0.46	0.49	0.47
Harvesting stage mean	0.61	0.60	0.60

CV (%) 4.8

Lsd $_{(0.05)}$ Genotype= 0.04 **Harvesting stage= 0.02** **Harvesting stage x genotype= 0.50**

4.6.7 Fats and Oils

Mean values of fat composition in seeds of the pepper genotypes are shown in Table 25. The genotype Ojemma had the highest crude fat composition of 10.52% of seed dry mass which was significantly different from the genotype Bird Beak which had the lowest mean composition of 0.92% of seed dry mass for seeds extracted from full ripe fruits. For seeds extracted from physiologically mature fruits with after ripening, the genotype Legon 18 had the highest crude fat composition of 7.66% of seed dry mass while Bird Beak again had the lowest value of 0.65%. The interaction effect was statistically highly significant (P<0.001) with Ojemma obtaining the highest mean composition of 8.89% and Bird Beak obtaining the lowest mean composition of 0.79% of seed dry mass (Appendix 27).

Table 25: Effect of genotype and harvesting stage on crude fat content (%) in seeds of the pepper genotypes

	Harvesting stage		
Genotype	**Full ripe**	**Physiologically mature**	**Genotype mean**
Bird Beak	0.92	0.65	0.79
Legon 18	8.11	7.66	7.88
Ojemma	10.52	7.25	8.89
Red Scotch Bonnet	1.94	1.06	1.50
Shito Adope	5.32	4.34	4.83
Harvesting stage mean	5.36	4.19	4.77

CV (%) 4.4

Lsd $_{(0.05)}$ Genotype= 0.25 **Harvesting stage= 0.16** **Harvesting stage x genotype= 0.35**

4.7 Estimation of Correlation Coefficient among the Genotypes of Pepper

4.7.1 Correlation Coefficient Estimation among Pepper Genotypes at Physiological Maturity

Correlation coefficients among selected agronomic and phytochemical traits of fruits at physiological maturity revealed an association between trait pairs (Table 26). There was highly significant and positive correlation between seed vigour and germination percentage (%G) (r = 0.994) and seed vigour and emergence (%E) (r = 0.932). Germination correlated positively with emergence (r = 0.933). A significant and positive correlation was observed in carbohydrate content (CHO) and 1000 seed weight (r = 0.607). There was very weak correlation between kaemferrol content (KAE) and percentage germination (r = 0.007) and percentage emergence (r = 0.0603). A positive association was observed between rutin content (Ru) and percentage germination (r = 0.164) and percentage emergence (r = 0.167). There was a positive correlation between quercetin content (Que) and seedling shoot length (r = 0.109), seedling root length (RL) (r = 0.292) and seedling girth (sg) (r = 0.237). Total phenols correlated positively with seedling shoot length (SL) (r = 0.274), seedling root length (RL) (r = 0.363) and seedling girth (sg) (r = 0.378).

However, a negative association was observed between certain trait pairs as shown in Table 27. A significantly negative correlation was observed between fat content and 1000 seed weight (r = -561). A negative correlation was recorded between trait pairs protein content and 1000 seed weight (r = -0.482), protein content and percentage emergence (%E) (r = -0.322) and protein content and percentage germination (%G) (r = -0.504). A negative association was observed between carbohydrate content in seeds (CHO) and seedling shoot length (SL) (r = -0.284), seedling root length (RL) (r = -0.435) and seedling girth (sg) (r = -0.426).

Table 26: Correlation coefficient estimates of some traits in seeds of pepper genotypes at physiological maturity

	Sg	RL	SL	TSW	% E	CHOs	FAT	% G	KAE	Pro	QUE	RU	SV
sg	-												
RL	0.8294	-											
SL	0.9072	0.7755	-										
TSW	0.1497	0.5956	0.4325	-									
% E	0.7108	0.7733	0.7174	0.644	-								
CHOs	-0.4254	-0.435	-0.2838	**0.6065**	**-0.0429**	-							
FAT	0.22	0.2205	0.0044	**-0.5607**	**-0.0668**	**-0.7203**	-						
% G	0.5877	0.6342	0.5129	0.6964	**0.9333**	0.0065	0.0421	-					
KAE	0.069	0.1483	0.0391	-0.2383	**0.0603**	-0.0744	0.0073	**0.0071**					
Pro	-0.0072	0.0192	0.0595	-0.4818	**-0.3223**	-0.5112	-0.0816	**-0.5035**	-0.121	-			
QUE	0.2371	0.2921	0.1085	-0.6544	**-0.0425**	-0.6766	0.6104	**-0.0784**	0.7415	0.1251	-		
RU	0.3724	0.4257	0.2125	-0.4896	**0.167**	-0.6546	0.6652	**0.1635**	0.7118	-0.0534	0.9645	-	
SV	0.6023	0.6365	0.5317	0.7284	**0.9318**	0.029	-0.0237	**0.9935**	-0.0308	-0.4582	-0.1378	0.1011	-

Values in bold are different from 0 at significance level of 0.05. TSW = 1000 seed weight, %E = Emergence percentage, CHOs = Carbohydrate content, %G = Germination percentage, KAE = Kaemferrol, Pro = Protein, QUE = Quercetin, Ru = Rutin, SV = Seed vigour, SL = Seedling shoot length, RL = seedling root length, sg = seedling girth

4.7.2 Correlation Coefficient Estimation among Pepper Genotypes at Full Ripe Stage

Correlation coefficients among selected agronomic and phytochemical traits of fruits at full ripe stage revealed an association between trait pairs (Table 27). There was highly significant and positive association in seed vigour and germination percentage (%G) (r = 0.945) and emergence (%E) (r = 0.771). A positive correlation was also observed between germination and emergence (r = 0.858). A significant and positive correlation was observed between carbohydrate content (CHO) and 1000 seed weight (r = 0.87). A positive correlation was seen in protein content (PRO) and percentage germination (r = 0.277), percentage emergence (%E) (r = 0.411), seedling shoot length (SL) (r = 0.508), seedling root length (RL) (r = 0.44) and seedling girth (sg) (r = 0.204).

However, a negative association was observed between certain trait pairs as shown in Table 28. A significantly negative correlation was seen between fat content and 1000 seed weight (r = -0.673). There was negative association between protein content (PRO) with 1000 seed weight (r = -0.493). Correlation analysis showed a negative correlation between carbohydrate (CHO) and seedling shoot length (SL) (r = -0.03), seedling root length (RL) (r = -0.239) and seedling girth (sg) (r = -0.009).

Table 27: Correlation coefficient estimates in some traits among pepper genotypes at both physiological maturity and full ripe stage

	sg	RL	SL	TSW	%E	CHOs	FAT	%G	KAE	Pro	QUE	Ru	SV	TPhe
sg	-													
RL	0.5598	-												
SL	**0.7588**	**0.8197**	-											
TSW	0.1608	-0.0979	0.024	-										
%E	0.4535	0.4064	0.4918	-0.2362	-									
CHOs	**-0.0086**	**-0.2393**	**-0.0298**	**0.8697**	-0.217	-								
FAT	**0.1715**	**0.2499**	**0.0276**	-0.6727	0.3597	**-0.8867**	-							
%G	**0.6112**	0.3807	0.5689	0.2013	**0.8584**	0.1727	0.0458	-						
KAE	**-0.4452**	**-0.0685**	**-0.3085**	**-0.8113**	-0.2994	**-0.7558**	0.4775	**-0.6981**	-					
Pro	**0.2042**	**0.4399**	**0.508**	-0.4929	0.4114	-0.5534	0.2981	0.2767	0.2472	-				
QUE	**-0.5616**	**-0.2713**	**-0.5412**	**-0.5987**	-0.4534	**-0.5229**	0.3887	**-0.8045**	**0.8827**	-0.2194	-			
Ru	**-0.4574**	**-0.2062**	**-0.4676**	-0.3609	**-0.7325**	-0.4579	0.3055	**-0.9146**	**0.7849**	-0.132	**0.8418**	-		
SV	0.5033	0.2509	0.4834	0.3267	**0.7709**	0.4055	-0.1895	**0.9451**	**-0.7708**	0.0655	**-0.7818**	**-0.9693**	-	
Tphe	**0.3642**	**0.0534**	**0.2965**	0.6222	0.5086	**0.7147**	-0.4694	**0.7817**	**-0.9138**	-0.2376	**-0.795**	**-0.9202**	**0.9105**	-

Values in bold are different from 0 at significance level of 0.05. TSW = 1000 seed weight, %E = Emergence percentage, CHOs = Carbohydrate content, %G = Germination percentage, KAE = Kaemferrol, Pro = Protein, QUE = Quercetin, Ru = Rutin, SV = Seed vigour, SL = Seedling shoot length, RL = seedling root length, sg = seedling girth, TPhe = Total phenol

4.7.3 Correlation among Pepper Genotypes at both Physiological Maturity and Full Ripe Stage

Correlation among agronomic characters and phytochemical traits of pepper determined over both physiological maturity and full ripe harvesting stages are shown in Table 28. Significantly positive association was observed between trait pairs carbohydrate content (CHO) and 1000 seed weight (TSW) (r = 0.687), percentage germination (%G) and percentage emergence (%E) (r = 0.9), seed vigour (SV) and percentage germination (%G) (r = 0.962), and seed vigour (SV) and percentage emergence (%E) (0.849). Protein content (Pro) correlated positively with seedling shoot length (SL) (r = 0.263), seedling root length (RL) (r = 0.197) and seedling girth (sg) (r = 0.094).

On the other hand, a significant negative association was observed in kaemferrol content (KAE) and 1000 seed weight (TSW) (r = -0.448), and percentage germination (%G) (r = -0.401) and percentage emergence (%E) (r = -0.156). There was a negative correlation between rutin content (Ru) and 1000 seed weight (TSW) (r = -0.446), percentage germination (%G) (r = -0.442) and percentage emergence (%E) (-0.281). A negative association was also observed in carbohydrate content (CHO) and seedling shoot length (SL) (-0.128), seedling root length (RL) (r = -0.365) and seedling girth (sg) (r = -0.22).

Table 28: Correlation coefficient estimates among pepper genotypes at both physiological maturity and full ripe stage

	GIRTH	**RL**	**SL**	**TSW**	**%E**	**CHOS**	**FAT**	**%G**	**KAE**	**Pro**	**QUE**	**RU**	**SV**	**Tphe**
GIRTH	-													
RL	**0.735**	-												
SL	**0.8722**	**0.7637**	-											
TSW	0.2544	0.0354	0.2584	-										
%E	**0.6331**	**0.5646**	**0.6487**	**0.4884**	-									
CHOs	-0.2195	-0.3651	-0.1278	**0.6865**	0.0299	-								
FAT	0.2174	0.2125	0.0511	-0.313	0.2087	**-0.6769**	-							
%G	**0.5793**	**0.4218**	**0.539**	**0.5962**	**0.9**	0.2031	0.1189	-						
KAE	-0.1403	0.0702	-0.1202	-0.4479	-0.1563	-0.372	0.2236	**-0.4005**	-					
Pro	0.0943	0.1971	0.2626	-0.2926	0.1055	**-0.4592**	0.1705	0.038	0.079	-				
Que	-0.0951	0.0703	-0.1758	**-0.5478**	-0.2742	**-0.6089**	0.4467	**-0.5021**	**0.8148**	-0.092	-			
Ru	0.0423	0.2014	-0.0734	-0.4457	-0.2805	**-0.5963**	0.4224	**-0.4416**	**0.7516**	-0.1057	**0.9029**	-		
SV	**0.5469**	**0.3956**	**0.5125**	**0.585**	**0.8494**	0.2827	-0.056	**0.9615**	**-0.4573**	-0.0813	**-0.5243**	**-0.497**	-	
TPhe	**0.377**	0.2651	0.2878	-0.0419	**0.2052**	-0.3423	0.1311	0.3289	**-0.5157**	0.1575	-0.119	-0.1342	0.3948	-

Values in bold are different from 0 at significance level of 0.05. TSW = 1000 seed weight, %E = Emergence percentage, CHOs = Carbohydrate content, %G = Germination percentage, KAE = Kaemferrol, Pro = Protein, QUE = Quercetin, Ru = Rutin, SV = Seed vigour, SL = Seedling shoot length, RL = seedling root length, sg = seedling girth, TPhe = Total phenol

CHAPTER FIVE

5.0 DISCUSSION

5.1 Vegetative Growth Characteristics

Variations were observed among genotypes in plant height, number of leaves and number of branches at different growth stages on the field. The genotypic makeup of the various pepper varieties could account for the differences observed. It has been reported that the ultimate plant height attained by different lines depended greatly on their growth characters (Tindall, 1983). Similarly, Vos and Frinking (1997) and El-Tohamy *et al.* (2006) reported that increase in plant height could be due to varietal variability to absorb nutrients from the soil. Red Scotch Bonnet had the highest mean height of 32.53cm at physiological maturity. This conforms to the findings of Nkansah *et al.* (2011) and Nsabiyera *et al.* (2012) who reported that the average plant height of pepper at maturity ranges from 32.1cm – 68.3cm. Generally, the genotypes used in the study were short which is desirable as short plants have the ability to withstand lodging (Nkansah *et al.,* 2011). An optimum plant height is reported to be positively correlated with the productivity of the plant (Khan *et al.,* 2009).

The mean stem girth of the genotypes observed ranged from 0.32cm to 0.27cm. This was inconsistent with the findings of Berhanu *et al.,* (2011) who reported a range of 0.72 cm to 1.24 cm. The lower range observed in this study could be attributed to environmental influence as the growing period was in the off-season. Branch numbers varied greatly among genotypes being more profuse in Shito Adope than the others. The variations observed could be attributed to the genetic make-up of the varieties studied as variety has been found to be one of the major factors that determine the number of primary branches in hot pepper (Delegen, 2014). Leaf numbers per plant among the genotypes used in the study varied, with genotype Shito Adope having the highest leaf numbers. The resources and energy necessary for building up structures in plants is through the process of photosynthesis and the leaf is the main organ responsible for this process (Lenis *et al.,* 2006). The smallest quantity of photosynthate produced and consequently yield has been reported to correspond to leaf numbers (Lahai *et al.,* 2013).

5.2 Reproductive Growth and Seed Characteristics

The mean number of days to 50% flowering among the genotypes was between 38 days and 56 days which is in consonance with the range reported by Pandit and Adhikary (2014). It has been reported that number of days to flowering in many plants is influenced strongly by their genotypic make-up (Rahman and Bahl, 1986; Thurling and Ratinam, 1989). Delelegn *et al.* (2014) also observed that earliness or lateness to 50% flowering in crops could be due to characters inherited and their ability to quickly adapt to the growing environment to promote their growth and development. Hence the variations observed could be due to inherent differences in the genotypes. Time of flowering is a very important trait in production as it influences fruit set and yield (Ishiyaku *et al.,* 2005; Ferrara *et al.,* 2011). The genotype Shito Adope which recorded the earliest days to 50% flowering could be useful in breeding for earliness. Days to 50% fruiting also varied among genotypes. The earliness of Shito Adope to flower corresponded to its relatively fewer number of days to reach 50% fruiting. Flower formation and fruit set has been indicated to be dependent on the interaction of a complex of processes influenced by genetic and environmental factors (Uarrota, 2010).

Mean seed numbers per fruit and seed weight varied significantly among the genotypes, harvesting stage and genotype x harvesting stage interaction. The differences observed as a result of varietal effects could be attributed to the genetic composition of the genotypes. In the present study, Bird Beak performed better than all the other genotypes in terms of number of seeds per fruit for both harvesting stages having a higher number in fruits harvested at full ripe than those harvested at physiological maturity. The genotype Shito Adope had the highest seed weight for seeds harvested at both full ripe and physiological maturity stages being higher in full ripe fruits than in physiological mature fruits. Fruits with higher seed weight generally can be considered as receiving a greater proportion of assimilates indicating that the combined effect of seed weight and seed number could be important in improving fruit quality which these two parameters an important economic part of the crop (Powell and Matthews, 1995; Bosland and Votava, 2000). Nkansah *et al.* (2011) reported a positive correlation between seed weight and food reserves in *Capsicum* species suggesting that heavier seeds tend to be viable for longer periods than less heavier ones. Percentage germination in seeds has been reported to be at its peak when 1000-seed weight of pepper are at their maximum (Naik *et al.*, 1996). Seed size and weight are therefore, very important parameters as they determine food reserved within the seed coat and influence germination and vigour.

5.3 Germination and Seed Vigour as Affected by Genotype and Harvesting Stage

Germination and seedling development vary in a genus or different species (Harbone, 1988; Hoffmann *et al.,* 2004; Ferreira *et al.,* 2005). Most of the nutrients essential for initial seedling development in several species is contained in food reserves stored in the endosperm of the seed (Perata *et al.*, 1997). In the current study, seeds from full-ripe fruits showed a higher germination and seed vigour than from half ripe/ physiologically mature fruits that had gone through after ripening. This agrees with the findings of Cavero *et al.* (1995) who stated that seeds extracted from physiologically mature fruits have poorer germination than seeds from full-ripe fruits. In *Capsicum* species, the quality of seed has been reported to be dependent on how matured and red the fruit is (Lysenko and Butkevich, 1980). Maximum germination and vigour has been reported in *Capsicum* species when seeds are extracted from fruits that have ripened to full red ripe colour (Demir and Ellis, 1992; Goncalves and Oliveira 1998; Oliveira *et al.,* 1999)

5.4 Emergence and Early Seedling Performance as Affected by Genotype and Harvesting Stage

It was confirmed that maturity stage of the fruits from the genotypes at the time of seed extraction had an influence on emergence and performance of the seedling before transplanting. Percentage emergence, seedling shoot length, diameter and root length for all the genotypes studied were significantly higher in seeds from full-ripe fruits than in seeds from physiologically mature fruits that had gone through after ripening. This is similar to what Krishnamurthy (1995) reported earlier that germination, field emergence, shoot length, root length and vigour index were higher in seeds harvested from fruits that had obtained maximum red colour than those harvested earlier.

5.5 Effect of Genotype and Harvesting Stage on Total Phenols and Flavonoids Content in Seeds of the Pepper Genotypes

Quercetin, kaemferrol, myrcetin and rutin are among the flavonoids present in vegetables (Holden *et al.,* 2002). The amounts of these compounds vary among genotypes due to differences in genetic make-up, conditions in the growth environment, fruit ripening stage and storage (Zhang and Hamauzu, 2003; Marinova *et al.,* 2005; Navarro *et al.,* 2006). In the present study, amounts of flavonoids in seeds of the genotypes varied significantly with different maturity stages. Rutin, quercetin and kaemferrol contents were higher in seeds extracted from physiologically mature fruits that had gone through after ripening than in seeds from full ripe fruits for Bird Beak, Legon 18, Ojemma and Shito Adope. However in Red Scotch Bonnet, the concentrations of these flavonoids were higher in seeds extracted from full ripe fruits than in seeds extracted from physiologically mature fruits that had gone through after ripening. The variations observed could be as a result of differences in genetic composition of the different pepper genotypes evaluated. Total phenolic compounds varied significantly among genotypes and harvesting stages. Results showed Legon 18 to be a better source of phenols as compared to the other genotypes being highest in seeds extracted from physiologically mature fruits that had been after ripened to full ripe. For seeds extracted from full ripe fruits, Shito Adope had comparatively higher amounts of total phenols. Supathra *et al.* (2013) reported that varying compositions of these compounds could be influenced by genotypic factors, extraction method, temperature, processing and conditions in storage.

5.6 Effect of Genotype and Harvesting Stage on Food Reserves in Seeds of the Pepper Genotypes

From previous studies carbohydrates, proteins and lipids have been identified as the major food reserves present in seeds (Bewley 1997, Suda and Giorgini 2000, Lima *et al.*, 2008). These food reserves are stored towards the latter stages of seed formation. Significant variations were observed in the composition of food reserves among genotypes and harvesting stages for the pepper genotypes studied. Carbohydrate composition was comparatively higher in Shito Adope and Bird beak than the other genotypes for seeds extracted from full ripe fruits without after ripening. The genotype Red Scotch Bonnet however had the highest carbohydrate content for seeds extracted from physiologically mature fruits that had been after ripened to full ripe. Generally, carbohydrate content was higher in seeds harvested from fully ripe fruits without after ripening for all genotypes with the exception of Red Scotch Bonnet. These variations could be due to the different genetic constitution of the varieties studied. The next abundant food reserve in seeds of the pepper genotypes studied was fats. Again, there were significant variations in genotypes and harvesting stages for amounts of fats present in seeds of the pepper genotypes. The fat content in seeds were generally higher in seeds extracted from full ripe fruits. As a major food reserve, lipids perform function as source of fuel for germination and seedling development (Nara *et al*., 2011).

Crude protein amounts also varied significantly among genotypes but not in harvesting stages. The different harvesting stages did not influence protein contents in the pepper genotypes. Differences among genotypes observed could be due to the genetic make-up of the genotypes studied. The higher protein content observed in some genotypes however, did not translate to better germination and vigour indicating that they are not strongly involved in germination and seedling development of *Capsicum species* (Table 29).

5.7 Character Association of Traits among Pepper Genotypes

Many important traits in crops exhibit either a negative or positive association because they are controlled by the same gene or are related developmentally or structurally (Falconer and Mackay, 1996). It is essential therefore, to know of traits that are correlated in order to determine whether or not selection for a particular trait will affect another (Girdthai *et al*., 2012).

From the findings in the study, seed vigour showed a positively significant correlation with germination percentage and emergence percentage irrespective of the stage of maturity of the fruit from which seeds were taken from. This is in conformity with the findings of Schuch *et al*., (2000) and Vaz mondo *et al*., (2013) who reported that seeds with low vigour often resulted in reduced germination, seedling emergence and early growth performance in most crops. For optimum field establishment, indirect selection of any of these factors that contribute to field performance could be effective. Again, a positive correlation was observed between percentage germination and seedling emergence. This agrees with the findings of Freitas *et al.*, (2000) who reported high correlation between standard germination and seedling field emergence in different cultivars of cotton. Standard germination results can therefore be a good indicator in predicting field emergence. Carbohydrate content also correlated positively with thousand seed weight, germination percentage and emergence percentage. This positive association shows that reserves stored in seeds, including carbohydrate, play a major role in germination and seedling development. Perata *et al*., (1997) earlier reported similar findings that the reserves stored in seeds of several species contain most of the essential nutrients necessary for early growth and development of seedlings. Indirect selection for carbohydrate, germination and emergence could therefore be effectively carried out.

Similarly, protein content correlated positively with germination, emergence, seedling shoot length, and seedling root length and seedling girth in seeds harvested from full ripe fruits but negative association in seeds from physiologically mature fruits. This implies that indirect selection for these traits to maximize protein content would be effective in full ripe fruits but not in physiologically mature fruits. Total phenols associated negatively with kaemferrol, quercetin and rutin content at both harvest maturity stages. The correlation analysis reveals that genotypes with high amount of phenols have minimal amounts of these kaemferrol, quercetin and rutin. Indirect selection of one trait would not be effective in improving the other.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

In this study, five pepper genotypes were used to evaluate the effect of harvesting stages and after ripening on germination and early seedling development. From the series of experiments conducted, the following conclusions could be drawn.

Shito Adope performed better than the other four genotypes in terms of vegetative and yield parameters including number of branches, stem girth, number of leaves, number of fruit and fruit weight per plant with the exception of plant height. Shito Adope again took fewer number of days to attain 50% flowering and fruiting, an indication of early maturity. Seed numbers and weight were higher in fruits harvested at full ripe than in fruits harvested at physiological maturity for all genotypes.

The two different harvesting stages affected germination and seedling development in all the genotypes. Higher germination percentages and vigour were observed in seeds extracted from fully ripe fruits than those extracted from physiologically mature fruits that had been after ripened in all the genotypes. However, better seedling development was observed in physiologically mature fruits with after ripening in the genotypes Shito Adope and Bird beak. Among the genotypes studied, higher food reserves were observed in seeds extracted from full ripe fruits than from physiologically mature fruits which could have accounted for the higher germination percentages recorded in full ripe seeds. Total phenols were also higher in seeds from full ripe fruits for all genotypes. Flavonoid contents however varied among genotypes and harvesting stages. The genotypes Shito Adope, Bird beak and Legon 18 had higher rutin, quercetin and kaemferrol amounts in seeds from physiologically mature fruits with after ripening. In conclusion, for better germination and vigour, extraction of pepper seeds from half ripe fruits should be avoided.

6.2 Recommendations

Based on findings from this study, I recommend that:

- For good germination and emergence, seeds should be extracted from fruits that have been allowed to mature to full ripe on the field. After ripening could however be employed to improve germination and seed quality of fruits accidentally harvested at half ripe.
- Further research should be done on the genotypes to evaluate the effect of the different harvesting stages on field performance, fruit yield and seed yield.
- Further studies should be conducted to find out the levels of the plant hormones (Gibberellic and Abscisic acid) that affect seed development and germination in the pepper seeds extracted at various maturity stages.
- Fruits at physiological maturity and full ripe stage could be after ripened to soft ripe stage and then seeds extracted and assessed for germination, seedling performance, growth and yield.
- Seeds extracted from different fruit maturity stages of the pepper genotypes could be further studied for effect of storage duration on seed quality.

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APPENDICES

Appendix 1: Analysis of variance table for mean plant height

Variate: PLANT_HEIGHT_cm

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	90.423	30.141	3.46	
REP.*Units* stratum					
GENOTYPES	4	210.124	52.531	6.04	0.007
Residual	12	104.435	8.703		
Total	19	404.982			

Appendix 2: Analysis of variance table for mean stem girth

Variate: STEM_GIRTH_mm

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	0.1754	0.0585	0.39	
REP.*Units* stratum					
GENOTYPES	4	0.8136	0.2034	1.37	0.303
Residual	12	1.7877	0.1490		
Total	19	2.7767			

Appendix 3: Analysis of variance table for mean number of leaves per plant

Variate: NUMBER_OF_LEAVES

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	345.45	115.15	2.61	
REP.*Units* stratum					
GENOTYPES	4	2132.30	533.08	12.07	<.001
Residual	12	530.01	44.17		
Total	19	3007.76			

Appendix 4: Analysis of variance table for number of branches per plant

Variate: BRANCHES

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	30.514	10.171	3.72	
REP.*Units* stratum					
GENOTYPES	4	75.410	18.853	6.90	0.004
Residual	12	32.801	2.733		
Total	19	138.725			

Appendix 5: Analysis of variance table for days to 50% flowering

Variate: DAYS_TO_50%_FLRG

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	8.550	2.850	0.37	
REP.*Units* stratum					
GENOTYPES	4	1210.300	302.575	39.60	<.001
Residual	12	91.700	7.642		
Total	19	1310.550			

Appendix 6: Analysis of variance table for days to 50% fruiting

Variate: DAYS_TO_50%_FRUITING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1257.80	419.27	4.26	
REP.*Units* stratum					
GENOTYPES	4	7012.70	1753.17	17.80	<.001
Residual	12	1181.70	98.47		
Total	19	9452.20			

Appendix 7: Analysis of variance table for seed number per fruit

Variate: SEED_NO_FRUIT

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	5330.15	1332.54	51.09	<.001
HARVESTING_STAGE	1	2371.60	2371.60	90.92	<.001
GENOTYPES.HARVESTING_STAGE	4	629.65	157.41	6.03	0.001
Residual	30	782.50	26.08		
Total	39	9113.90			

Appendix 8: Analysis of variance table for mean seed weight

Variate: %1000_SEED_WT

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	27.24259	6.81065	84.28	<.001
HARVESTING_STAGE	1	27.95584	27.95584	345.95	<.001
GENOTYPES.HARVESTING_STAGE	4	3.75006	0.93752	11.60	<.001
Residual	30	2.42430	0.08081		
Total	39	61.37279			

Appendix 9: Analysis of variance table for mean germination percentage

Variate: GERMINATION

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	23370.15	5842.54	308.45	<.001
HARVESTING_STAGE	1	6838.22	6838.22	361.01	<.001
GENOTYPES.HARVESTING_STAGE	4	1274.15	318.54	16.82	<.001
Residual	30	568.25	18.94		
Total	39	32050.78			

Appendix 10: Analysis of variance table for seed vigour

Variate: SEED_VIGOUR

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	22407.35	5601.84	312.95	<.001
HARVESTING_STAGE	1	3496.90	3496.90	195.36	<.001
GENOTYPES.HARVESTING_STAGE	4	1090.35	272.59	15.23	<.001
Residual	30	537.00	17.90		
Total	39	27531.60			

Appendix 11: Analysis of variance table for mean percentage emergence

Variate: %_Emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	24491.71	6122.93	111.85	<.001
HARVESTING_STAGE	1	6704.40	6704.40	122.48	<.001
GENOTYPES.HARVESTING_STAGE	4	3561.86	890.47	16.27	<.001
Residual	30	1642.22	54.74		
Total	39	36400.19			

Appendix 12: Analysis of variance table for seedling shoot length 3WAS

Variate: SHOOT_LENGTH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	23.3984	5.8496	8.16	<.001
HARVESTING_STAGE	1	4.5968	4.5968	6.41	0.017
GENOTYPES.HARVESTING_STAGE	4	4.0656	1.0164	1.42	0.252
Residual	30	21.5102	0.7170		
Total	39	53.5710			

Appendix 13: Analysis of variance table for seedling root length 3WAS

Variate: ROOT_LENGTH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	113.918	28.480	6.21	<.001
HARVESTING_STAGE	1	2.034	2.034	0.44	0.510
GENOTYPES.HARVESTING_STAGE	4	26.168	6.542	1.43	0.249
Residual	30	137.541	4.585		
Total	39	279.662			

Appendix 14: Analysis of variance table for seedling stem girth 3WAS

Variate: GIRTH_mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	4.2289	1.0572	2.03	0.115
HARVESTING_STAGE	1	1.6402	1.6402	3.15	0.086
GENOTYPES.HARVESTING_STAGE	4	10.2989	2.5747	4.95	0.003
Residual	30	15.6136	0.5205		
Total	39	31.7816			

Appendix 15: Analysis of variance table for seedling shoot length 4WAS

Variate: SHOOT_LENGTH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	72.263	18.066	7.91	<.001
HARVESTING_STAGE	1	11.870	11.870	5.20	0.030
GENOTYPES.HARVESTING_STAGE	4	12.038	3.010	1.32	0.286
Residual	30	68.480	2.283		
Total	39	164.651			

Appendix 16: Analysis of variance table for seedling root length 4WAS

Variate: ROOT_LENGTH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	299.61	74.90	4.69	0.005
HARVESTING_STAGE	1	12.95	12.95	0.81	0.375
GENOTYPES.HARVESTING_STAGE	4	49.48	12.37	0.77	0.551
Residual	30	479.50	15.98		
Total	39	841.54			

Appendix 17: Analysis of variance table for seedling girth 4WAS

Variate: GIRTH_mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	3.6537	0.9134	7.42	<.001
HARVESTING_STAGE	1	0.5476	0.5476	4.45	0.043
GENOTYPES.HARVESTING_STAGE	4	0.7479	0.1870	1.52	0.222
Residual	30	3.6953	0.1232		
Total	39	8.6445			

Appendix 18: Analysis of variance table for seedling shoot length 5WAS

Variate: SHOOT_LENGTH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	177.539	44.385	17.04	<.001
HARVESTING_STAGE	1	11.172	11.172	4.29	0.047
GENOTYPES.HARVESTING_STAGE	4	20.643	5.161	1.98	0.123
Residual	30	78.156	2.605		
Total	39	287.510			

Appendix 19: Analysis of variance table for seedling root length 5WAS

Variate: ROOT_LENGTH_cm

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	742.67	185.67	11.86	<.001
HARVESTING_STAGE	1	8.42	8.42	0.54	0.469
GENOTYPES.HARVESTING_STAGE	4	51.37	12.84	0.82	0.522
Residual	30	469.54	15.65		
Total	39	1272.00			

Appendix 20: Analysis of variance table for seedling girth 5WAS

Variate: GIRTH_mm

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	11.3234	2.8309	17.14	<.001
HARVESTING_STAGE	1	0.4121	0.4121	2.49	0.125
GENOTYPES.HARVESTING_STAGE	4	2.4766	0.6191	3.75	0.014
Residual	30	4.9556	0.1652		
Total	39	19.1677			

Appendix 21: Analysis of variance table for rutin content

Variate: Rutin_Conc_mg_100ml

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
GENOTYPES	4	148.60333	37.15083	1031.97	<.001
HARVESTING_STAGE	1	14.56033	14.56033	404.45	<.001
GENOTYPES.HARVESTING_STAGE	4	225.33133	56.33283	1564.80	<.001
Residual	20	0.72000	0.03600		
Total	29	389.21500			

Appendix 22: Analysis of variance table for quercetin content

Variate: Quercetin_Conc_mg_100ml

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	52.735704	13.183926	1483.19	<.001
HARVESTING_STAGE	1	1.825333	1.825333	205.35	<.001
GENOTYPES.HARVESTING_STAGE	4	34.422815	8.605704	968.14	<.001
Residual	20	0.177778	0.008889		
Total	29	89.161630			

Appendix 23: Analysis of variance table for kaemferrol content

Variate: Kaem_Conc_mg_100ml

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	165.693282	41.423321	10825.29	<.001
HARVESTING_STAGE	1	5.664328	5.664328	1480.28	<.001
GENOTYPES.HARVESTING_STAGE	4	70.904337	17.726084	4632.42	<.001
Residual	20	0.076531	0.003827		
Total	29	242.338478			

Appendix 24: Analysis of variance table for total phenols content

Variate: Total Phenol Concn

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	3.995E-01	9.989E-02	15153.06	<.001
HARVESTING_STAGE	1	4.728E-03	4.728E-03	717.21	<.001
GENOTYPES.HARVESTING_STAGE	4	6.597E-01	1.649E-01	25019.68	<.001
Residual	20	1.318E-04	6.592E-06		
Total	29	1.064E+00			

Appendix 25: Analysis of variance for carbohydrate content

Variate: CHOs_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	843.0880	210.7720	1700.22	<.001
HARVESTING_STAGE	1	93.5679	93.5679	754.78	<.001
GENOTYPES.HARVESTING_STAGE	4	191.6550	47.9138	386.50	<.001
Residual	20	2.4793	0.1240		
Total	29	1130.7902			

Appendix 26: Analysis of variance table for protein content

Variate: PROTEIN_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	0.2522250	0.0630562	74.14	<.001
HARVESTING_STAGE	1	0.0014469	0.0014469	1.70	0.207
GENOTYPES.HARVESTING_STAGE	4	0.0555672	0.0138918	16.33	<.001
Residual	20	0.0170106	0.0008505		
Total	29	0.3262496			

Appendix 27: Analysis of variance table for crude fat content

Variate: FAT_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPES	4	319.18130	79.79533	1843.62	<.001
HARVESTING_STAGE	1	10.27046	10.27046	237.29	<.001
GENOTYPES.HARVESTING_STAGE	4	8.78816	2.19704	50.76	<.001
Residual	20	0.86564	0.04328		
Total	29	339.10555			

Appendix 28: Prevailing average rainfall, relative humidity and temperature range during the study period.

Month	**Year**	**Rainfall**	**Relative humidity**	**Temperature (^0C)**	
				Max	**Min**
Dec	2016	20	80	29	23
Jan	2017	10	77	32	23
Feb	2017	20	78	32	24
Mar	2017	150	80	31	24
April	2017	190	82	31	23

Source: Ghana meteorological Service, 2016