MAIZE (*Zea mays* L.) SEED QUALITY IN RESPONSE TO SIMULATED HAIL DAMAGE

By

Silindile P. Miya

A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE (CROP SCIENCE)

Crop Science

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

November 2015

PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Professor Albert T. Modi

Date: 30 October, 2015

DECLARATION

I, Silindile Precious Miya, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: Silindile Miya

Date: 30 October, 2015

ACKNOWLEDGMENTS

A number of special acknowledgements deserve specific attention:

- National Research Foundation (NRF) and South African Society for Crop Production (SASCP) for funding my research.
- Prof. Albert Thembinkosi Modi, my supervisor, for providing me with this opportunity to further my studies and for his continuous guidance throughout my studies,
- Dr. Tafadzwa Mabhaudhi for always being available for consultation and for being a leader to be looked up to,
- Dr Samson Z. Tesfay for his guidance throughout all my plant physiology and biochemical lab work.
- My mentor, Tendai Polite Chibarabada, for guiding me through my studies to the best of her ability,
- All my colleagues and Crop Science post grads that were there for me and gladly helped me during the course of my study.
- My friends and family, for being there for me, supporting and encouraging me throughout the course of my study.

DEDICATION

To Zinhle Patricia Sithole, may her soul rest in peace and to my family; Lwanele Miya, Amanda Sithole and Philasande Sithole.

GENERAL ABSTRACT

Maize (*Zea mays* L.) is the most important cereal grain crop produced in various environments throughout South Africa. Maize is vulnerable to hail damage because it can reduce crop yield or may result in complete yield and quality loss. The objective of this study was to investigate the effect of simulated hail damage on maize physiology, growth, yield and seed quality of three popular maize cultivars [SC701, Mac Medium Pearl (MMP) and Zama Star (ZS)] at two different bioresource groups of KwaZulu-Natal (Swayimane and Baynesfield).Laboratory assessments were conducted using a completely randomised design replicated four times to test the seed quality (viability and vigour) before sowing. The three cultivars were analysed using tetrazolium, standard germination and electrolyte conductivity tests. Thereafter, a randomised complete block design replicated three times was used for the field experiments with three stages of simulated hail damage [control, V7 (9 weeks after planting) and VT (13 weeks after planting)] at three plant densities [(High) ca 65 000, (Moderate) 46 000, and (Low) 28 000 plants ha^{-1}]. Data collection included plant height, leaf number, PAR, LAI, stomatal conductance and chlorophyll content index. At harvest, ear prolificacy, cob mass, cob length, and seed mass were measured. After harvest, the maize cob was separated into two halves (Proximal and Distal) for seed position factor. Seed quality (viability and vigour) was then determined using a completely randomised design replicated four times for Tetrazolium (TZ) and standard germination (SG) tests. Vigour indices that were measured were germination vigour index, mean germination time, seedling length (shoot, root and total) and seedling mass (fresh and dry) as well as root to shoot ratio. Moreover, the seed nutritional content quality was determined for protein content.Based on seed qulity results, the cultivars that were planted differed significantly ($P<0.05$) with respect to seed moisture content, 1000 grain mass, germination rate, final germination, shoot length, seedling length, electrolyte conductivity, germination vigour index, mean germination time (days) and seedling root to shoot ratio. However, tetrazolium test, root length, seedling fresh and dry mass showed no significant differences ($P>0.05$) among cultivars. There was no agreement between seed viability and vigour tests. Results of viability tests showed that the superior maize cultivar was SC701 followed by ZS and MMP, respectively. In contrast, based on electrolyte conductivity test, MMP had superior seed vigour compared to ZS and SC701, respectively.

Field trial results showed that plant height varied significantly (P<0.05) between cultivars, sites and plant densities. The interaction between plant density and either hail damage or cultivar was significant (P<0.05) for plant height. Leaf number varied significantly (P<0.05) with respect to cultivars and plant density as well as the interaction of cultivars by site. The same was true for LAI. There were significant (P<0.05) differences between plant densities, sites, and their interaction for PAR. There were also significant (P<0.05) effects of cultivar by hail, plant density and site on stomatal conductance. Moreover, ear prolificacy was significantly (P<0.05) affected by site. Maize cob length was significantly (P<0.05) affected by cultivars, sites and interaction between cultivars and sites. After harvest, seed quality results indicated that there were significant effects (P<0.05) of plant density, seed position and BRG based on SG test. Proximal seeds had high seed quality with Baynesfield being the superior environment. Seeds from high plant density had superior quality with the best cultivar being SC701. Occurrence of hail damage at V7 or no hail damage was advantageous as expressed by standard germination and germination vigour. The TZ test showed that seed from Swayimane and applying hail damage at VT were more viable. There was a significant (P<0.05) interaction between cultivars, hail damage and plant density on seed protein content. Plants that were not subjected to hail damage, at low plant density and cultivar SC701had high seed protein content. It can be concluded from this study that stress caused by hail damage can influence seed quality. Management decisions such as planting dates, cultivar selection and plant population are important in mitigating hail damage effects on maize physiology, growth and yield. In addition to these management practices, seed selection based on the position on the cob is also an important determinants of maize seed quality. The findings of this study can be used to mitigate effects of hail damage on plant physiology and seed quality. Farmers from hail prone areas can select cultivar SC701, high plant density when growing their maize crops and select seeds form proximal part of the cob to use for the subsequent season. Further research can still be conducted on hail damage and other climate change induced environmental conditions on more than just the physiological seed quality and seed protein content. More research questions may be answered on biochemical, genetical and physiological stress indicators and mechanisms.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Rational for the Research

Climate change is one of the challenges that affect agriculture as a result of increasing temperatures and unpredictable rainfall, which have negative effects on crop productivity (Ngaira, 2007; Dewi, 2009; Porter *et al.*, 2014). It has been argued that some parts of the world such as the temperate regions (largely in the developed world) may benefit from some of the climate change effects whereas other regions (mainly the tropical and sub-tropical regions of the developing world) may be detrimentally affected (Cline, 2007; Dewi, 2009; Porter *et al.*, 2014). Hailstorms have been noted as a significant part of unpredictable weather conditions caused by climate change (Sisu *et al.*, 2011). Biological and physiological processes of plants may be negatively affected by stress conditions created by weather extremes such as hail storms. Many parts of the world have reported severe crop losses from hail damage (Lemons, 1942 Changnon, 1977; Botzen *et al.*, 2010; Bore *et al.*, 2011; Sisu *et al.*, 2011; Zhao *et al*, 2012). The incidence of hail storms is likely to increase in the future due to global warming which in turn will yield considerable losses in agriculture, particularly crop losses (Botzen *et al.*, 2010).

Maize (*Zea mays* L.) is among the world's leading crops used to provide a source of food, feed, fuel and fibre (Tenaillon and Charcosset, 2011). This crop offers economic value found in many maize parts such as the grain, tassel, stalk, leaves and cobs which can all be utilized in the production of a variety of food and non-food products. That is why maize, globally, is one of the most economically important crops after wheat and rice (Omara, 2013). Maize is an important staple crop in South Africa and many parts of the world, especially sub-Saharan Africa where it plays a vital role of food and nutrition security. Maize is also increasing in its importance as an industrial crop. Among other processed forms of the crop, there is now an increasing importance of maize in the industrial production of ethanol (Robertson *et al.*, 2011) as well as starch (du

Plessis, 2003). Therefore, among grain crops worldwide, maize plays a significant role in global trade and economy (White and Johnson, 2003).

Despite being an important crop worldwide, maize still faces various limiting factors to its production. Some of these are now being exacerbated by global climate change; this in turn is causing huge production losses and reduction of produce quality for both food and processed materials (Mirza, 2003). As a summer crop, maize is prone to hail damage which naturally occurs during warm seasons. According to Lemons (1942), among other cereal crops, maize is extremely susceptible to hail damage, while, wheat is the most resistant. The differences between maize and wheat may be explained by canopy characteristics such as the size of maize leaves and maize plant height relative to those in wheat. Hail induced plant injuries may be inflicted on the leaves, stalk, branches, or fruit (Lemons, 1942). Hail damage typically results in significant leaf damage and abscission which translates to loss in leaf area. Physiologically, the size of the plant's canopy can be directly related to the 'size' of its 'photosynthetic factory'. Thus, hail damage will result in reduced photosynthesis due to loss of leaf area. Due to the losses that may be incurred after hail damage, this phenomenon is socio-economically important. Not only does hail have deleterious effects on crop yield but also seed quality. Fewer returns for the farmer which is enhanced by reduced number of marketable produce may be evident after hail destruction to the crops. The consumers are also implicated after a hail event as they have to pay higher prices for less marketable products of maize.

Seeds are an important component of plant reproduction and dispersal to new locations (Ventura *et al*., 2012). Seeds are the basic foundation to crop production (Milosevic *et al*., 2010). In flowering plants the main reproductive strategy is the production of seed that ensures the survival and perpetuation of the species (Rajjou *et al*., 2012). Consequently, the seed production industry is important, whereby, seed science has the obligation of producing high quality seed characterized by good biochemical, physiological and phytopathological traits. This agricultural industry is highly profitable even though its activity occupies a small portion in terms of commercial production. The industry has highly significant financial effects; the global seed industry is estimated to be worth $36.5 billion (Milosevic *et al*., 2010). The principal contributor to the industry's success is seed quality that ensures superior performance of plants under various field conditions. Seed quality is vital especially since there is a need of producing large quantities of food to meet food security requirements for the increasing global population. If hail damage has a negative effect on photosynthesis and subsequently dry matter availability and partitioning during seed development, this could lead to negative effects on seed quality. In such cases the hail damage induced loss of seed quality would result in food insecurity owing to low yields and quality associated with using poor quality seed.

There is a large body of evidence about the importance of soil fertility, drought, poor management, weeds, diseases, and pests as factors affecting maize crop yield (Sakala and Kabambe, 2004), whereas, the effects of hail damage have not been widely reported. In addition, the objective of crop improvement usually prioritizes crop yield quality rather than seed quality. While the agronomic aspects of hail damage have been studied in other parts of the world, especially in the developed world, no studies have been published to show what effect hail damage has on seed quality especially with respect to maize crop in the developing world. There is, therefore, an apparent research gap that exists in seed science particularly in Southern Africa. The effect of hail damage is expected to differ depending on the stage of crop development. Genotype (cultivar) and management practices can mitigate the negative effects of hail damage. Although the effect of hail damage can be determined using indicators associated with growth, yield and quality of the harvested product, this study sought to focus on growth parameters, cob size and seed quality in relation to position on the cob.

1.2 Aims and Objectives

It was hypothesized in this study that simulated hail damage on the leaves has no effect on seed quality of maize. The general aim of the study was to determine the effect of hail on maize growth and seed quality.

1.2.1 Specific Objectives

A combination of factors that allowed for an investigation of hail damage with respect to the effects genotype, timing and agronomic management was considered to achieve the following objectives:

i. To determine the effect of hail damage on maize leaves in response to time of occurrence, namely seventh leaf (V7) compared with tasseling (VT) stage.
ii. To compare the effect of plant population on mitigation of hail damage in maize by comparing three planting densities, 28 000, 46 000 and 65 00 plants/ha.
iii. To compare the response of the maize cultivars SC701, Zama Star and Mac Medium Pearl to simulated hail damage in response to timing of damage and plant population as interacting management factors.
iv. To determine the effect of hail damage on maize cob size
v. To determine the effect of hail damage on seed quality in relation to viability, germination and nutritional content.

CHAPTER 2

LITERATURE REVIEW

2.1 Classification, history and origin

Maize (*Zea mays* L.), from the family Poaceae (Gramineae), tribe Maydeae (Sikandar *et al*., 2007) is a determinate annual C4 (tropical) crop that is tall, ranging between a height of 0.3 and 7 m (Ritchie and Hanay, 1982; McCann, 2005; O'Keefe and Schipp, 2009). The crop has an erectophile canopy architecture. This species is predominantly cross-pollinated (Smale, 2001) and consists of both the vegetative and reproductive growth phases in its life cycle (Ritchie and Hanay, 1982). Maize can be grouped into short, medium and long season cultivars depending on the genetics of the cultivar and the environmental conditions such as soil moisture and temperatures (Mallett, 1993). According to FAOSTAT (2012), relative to other cereal crops, maize ears and seed heads are larger. This may be due to the ability of this crop to adapt to various environments. Being a C4 plant, maize uses solar radiation, carbon dioxide (CO_2), nitrogen and water during photosynthesis more efficiently which allows for relatively higher yields compared to other major grain cereals such as wheat (du Plessis, 2003; O'Keefe and Schipp, 2009). The high desirability of maize is also attributed to the high energy and feed value of the kernel, stem and leaf (O'Keefe and Schipp, 2009). These factors, although not exhaustive, may explain why maize, of all the cereal crops, is the most widely grown crop around the world and the most extensively traded cereal after wheat and rice (Smale, 2001).

The plant root system is fine and profusely branched with root hairs. The mature maize plant has lateral and downward root growth of about 1.5 and 2 m or more, respectively. The plant also has adventitious roots (du Plessis, 2003). Typical of a grass leaf, the maize leaf has a sheath, ligule, blade and auricles. The leaf blade is characterized by being thin, long, undulating, glabrous to hairy and has a tapered tip. Along the entire length of the leaf is the supporting prominent mid-rib (du Plessis, 2003). The maize stem height ranges between less than 0.6 and 5 m and this characteristic is genotype specific. The cylindrical, solid stem which is clearly divided into nodes and internodes may have 8 to 21 internodes. The nodes below soil surface may give rise to the tillers. The main ear on the maize plant is borne from the lateral shoot approximately positioned on the bud from the eighth node above the soil surface (du Plessis, 2003). The plant has both the male and female flowers as separate inflorescences on the same plant thus referred to as a monoecious plant (Eubanks, 2001; du Plessis, 2003). The tassel bears the male flowers whereas the female flowers are borne on the ear (du Plessis, 2003).

The domestication of maize in central Mexico by the indigenous people dates back to between 6,000 and 10,000 years ago (Doebley, 2004; Tenaillon and Charcosset, 2011). This crop was domesticated from the subspecies *Zea mays* ssp., *Parviglumis* commonly known as teosinte (Ranere *et al*., 2009). It was human selection, cultivation and exploitation of natural recombinants between two wild grasses with novel features that were desirable to humans for food purposes that resulted in domesticated maize. Maize, moreover, evolved from its close wild grass relatives also found in the genus *Zea*. The species is also prevalent to Mexico where maize has originated (Eubanks, 2001). Therefore, the Mexican region is one of the major centres of maize diversity (Smale, 2001). The expansion of maize to various places has been accompanied by a dramatic environmental adaptation particularly with respect to plant cycle with adjustment of the growing season duration (Tenaillon and Charcosset, 2011).

There is a profound morphological differentiation from the wild progenitor to cultivated maize. The variation ranges from vegetative architecture modification such as the reduction in branching; ear morphology including the shape, number, size, position along vegetative axes, and number of rows per ear; kernel morphology including kernel shape, size, and hardness. The variations also include kernel characteristics such as dormancy, shattering, starch and protein content. In maize classification the ear features with kernels in situ are normally used. Therefore, a pronounced genetic biodiversity in maize becomes evident and very remarkable (Eubanks, 2001) from ear and kernel variations.

Maize is among the world's leading crops which are used as a source of food, feed, fuel and fibre (Tenaillon and Charcosset, 2011). According to Palagyi and Nemeth (1996), industrially, the importance of the crop is still increasing. The average yield of maize globally is approximately 3 t ha^{-1}. However, in the developed maize production areas such as the USA and France, the common average yield is greater than 8 t ha^{-1} (Palagyi and Nemeth, 1996). The USA ranks as the largest maize producer in the world with Europe, Africa and Latin America also producing large quantities of the crop (Adebisi *et al*., 2013). Between 2008 and 2010, maize world production was approximately 833 million metric tons harvested from an area of about 161 hectares (Omara, 2013). The developed countries produce more than 70% of this yield which is from less than 50% of the world total land under maize cultivation (FAO, 2012). However, in the third world, only 2 t ha^{-1} on average is considered a good yield. Technological advancement, good agronomic practices and the type of varieties used have an effect on these trends (Palagyi and Nemeth, 1996). In South Africa, the area under maize production for the year 2013 was about 2.8 million hectares and the final commercial crop production was about 11.7 million tonnes (Dredge, 2013). White maize accounts for about half the production used for human consumption (du Plessis, 2003).

2.2 Socio-economic importance

Maize is an important staple crop in most developing countries (Palagyi and Nemeth, 1996). Its global demand has been increasing, whereby in 2010, there was 40% maize demand of the world's major cereals. As a vital staple food for many poor regions of the world, the crop accounts for 73%, 46% and 44% of crop production in sub Saharan Africa, South Asia and Latin America, respectively (Omara, 2013). Maize plays a principal nutritional role in those regions as a staple diet to about 200 million people (du Plessis, 2003). This crop is especially important in the diets of rural people in the developing world (Smale, 2001; Omara, 2013). Not only is maize a major food and animal feed crop worldwide, it is also an important industrial grain crop (White and Johnson, 2003). In terms of animal feed, the crop ranks first place in international fodder production (Palagyi and Nemeth, 1996).

There is economic value found in all the maize parts such as the grain, tassel, stalk, leaves and cobs which can all be utilized in the production of food and non-food products (Adebisi *et al*., 2013). Industrially, there is now an increasing importance of maize in ethanol and starch production (du Plessis, 2003; Robertson *et al*., 2011). The starch from the kernels can be found in food products, in clothing products and can be used in the pharmaceutical industry for making tablets. Starch can further be used for paper production, sweeteners, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint after processing. The developed world has an accelerated interest in utilizing maize for manufacturing ethanol as part of efforts to replace fossils fuel and using bio-fuels (Persson *et al*., 2009). This has increased the demand for maize resulting in an increase in producer prices (Omara, 2013). Moreover, oil from the seeds after processing can be used as cooking material, margarine and in salad dressing, whereas, the soluble parts of the maize kernel are utilized in animal and poultry feed together with proteins and hulls (du Plessis, 2003).

Of all the cereal crops, maize is the most widely grown crop around the world and the most extensively traded cereal after wheat and rice (Smale, 2001). This may be due to its adaptability to various environments. Maize uses solar radiation more effectively which enhances highest yields compared to other grains cereals. The crop is also a vital grain crop in South Africa where it is grown under diverse environments throughout the country (du Plessis, 2003). The importance of maize is also evident in the livelihoods of many peasant farmers in the third world. This crop serves as a source of GDP for many world nations. For some farmers in developing countries, the returns from the crop serve as the only source of income.

2.3 Maize growth and development

Maize is a monoecious crop characterized by having both male and female flowers (spikelets) distinctly found on the same plant (Eubanks, 2001). Although a monoecious crop, maize is predominantly cross-pollinated (Smale, 2001). It has both vegetative and reproductive growth phases in its life cycle (Ritchie and Hanay, 1982; Salvador, 1988; O'Keefe, 2009 and Schipp, 2009). Maize plant requires specific conditions for it to grow and survive during its growing season. One of the prerequisites for maize growth is warm weather, optimally between 24-30ºC, which is usually considered to be advantageous for maize growth (Visher, 1940, Smith, 1993). The crop is intolerant to frost damage which may kill it; hence, the crop requires a long frost free period for growth. Moreover, maize requires considerable amount of water since drought can be detrimental for its growth and development (Visher, 1940). Furthermore, a maize plant grown under dry land requires approximately 500-700 mm of rain over the growing season, which is October to March, for good yield (Smith, 1993). At tasseling the crop experiences peak demand for water and nutrients (Smith, 1993; du Plessis, 2003). According to Smith (1993), water stress at this stage may reduce yield by 8% for each day of stress.

With all the requirements for maize growth being met, the life cycle starts from the planting of seed to physiological maturity of the plant (O'Keefe, 2009). This life cycle can be divided into agricultural and biological life cycle. The stages of agricultural life cycle in maize start from planting to germination, emergence, vegetative growth, reproductive development, and finally harvest. However, the biological life cycle begins with the formation of a zygote after sexual fertilization (Salvador, 1988). In its life cycle, maize further has distinct vegetative and reproductive growth phases (Salvador, 1988; O'Keefe and Schipp, 2009). The initiation and development of all the morphological configurations related with the maize plant that is mature are carried out by vegetative growth phase. This growth stage is characterized by many nutrient sinks such as leaves, stems branches and roots and consequently high nutrient uptake (Salvador, 1988; O'Keefe, 2009). At this stage there is rapid plant growth where the plant begins the storage of nutrients for the rest of the life cycle. The stage is influenced by water, temperature, solar radiation interception and photosynthesis (O'Keefe, 2009). The determination of vegetative growth stages is expressed by leaf collar method depending on the leaf collars that are visible. The stages defined by this method are designated V stages. For instance, at stage V7 there would be seven leaf collars that are visible on the plant (O'Keefe and Schipp, 2009).

The reproductive stage, commonly denoted as R stage, starts from the transition that takes place from conspicuous tassel disclosure and pollen shedding after sufficient stem elongation and silking (Salvador, 1988; O'Keefe and Schipp, 2009). By the time the plant ceases vegetative growth into pollination it would have reached maximum leaf number and stalk size. Moreover, it is at this point that the plant tissue's metabolic activity is at peak. There is also a redirection of the resources from vegetative growth to pollination and kernel formation after the reproductive stage is reached (O'Keefe, 2009). Shortly after the silking stage in maize, a new individual (seed) is formed after male and female gametes have fused during fertilization (Salvador, 1988). The commencement of seed development soon after fertilization starts with the seeds at the base of the ears being fertilized first and those at the tip fertilized last. The assessment of reproductive stages only takes into consideration the seeds at the middle of the ear (O'Keefe and Schipp, 2009).

2.3.1 Vegetative growth stages

There are several stages under maize vegetative growth starting from VE (germination and emergence) to VT (tasseling). The first stage of growth is at VE, from the planting of seed to emergence of the coleoptile which takes about six to ten days after planting under warm and moist conditions (du Plessis, 2003; O'Keefe, 2009). du Plessis (2003) and O'Keefe (2009) reported that for the germination process which takes about 2-3 days, optimum temperatures between 20 and 30ºC and soil water content of about 60% are required. These authors also reported that at stage VE, after the coleoptile has emerged, it splits at the tip and unfolds into two true leaves. After the VE stage is stage V1-V2 which occur when 1-2 leaves are visible on the stem and there is still a relatively small primary root system. This stage occurs in about one week after plant emergence. At this stage, the plant still requires small amounts of nutrients. Thereafter, at approximately two weeks after emergence, the plant enters stage V3 (O'Keefe, 2009). The growth of seedling root system has stopped and the major part of the root system now has the nodal roots that now serve as the major part. By stage V5 the leaf and ear shoot initiation has been accomplished (O'Keefe, 2009).

The number of kernel rows around the ear is determined at stage V5-V8. About 700-1000 potential kernels or ovules arranged at 35 per row on the cob can be found on the well-developed cob (O'Keefe, 2009). According to O'Keefe (2009), there can be about 12-24 rows on the maize cob. Stem mass is also increased by about 50 to 100 times (du Plessis, 2003; O'Keefe, 2009). At stage V5 the determination of the potential ear shoot number commences (O'Keefe, 2009). Moreover, tiller development has already commenced at this stage where the growth point above the soil surface is about 5-7.5 cm and the plant is about 20 cm in height (du Plessis, 2003). The growing point below the soil surface will not be damaged by frost or hail but the exposed leaves. However, very little final yield reduction will be accomplished by leaf damage at this stage. The plant reaches stage V6 approximately three weeks after emergence (O'Keefe, 2009). There is well distribution of the root system on the soil with extension of 45 cm deep and 60 cm to the sides. The amount of nutrients that the plant now absorbs is greater than in earlier stages. The tassels also initiate following this stage (O'Keefe, 2009).

From stage V7 until pollination the plant establishes kernel numbers along the ear. The plant enters stage V8 approximately four weeks after plant emergence where several ear shoots are visible (O'Keefe, 2009). From six to eight nodes above the soil surface lateral shoots where cobs are borne develops rapidly (du Plessis, 2003; O'Keefe, 2009). According to O'Keefe (2009), the ear shoots that form harvestable ears eventually are only the upper one or two ears. However, prolific hybrids have a tendency of forming more than one harvestable ear. About 10-20% final grain yield reduction may result from the removal of expanded leaves by frost or hail (O'Keefe, 2009).

Moreover, from stage V10 –V17 there is determination of two yield components such as the ear size and the potential number of kernels. Growth stage V10 commences at about ten weeks after the plant has emerged. The rapid accumulation of nutrients that is evident at this stage is coupled with rapid dry matter accumulation (O'Keefe, 2009). Not only the soil nutrients are in high demand at this stage but also soil water that will accommodate the increased growth rate. The growth and development of the ear will in turn be influenced by these factors. Stage V12 follows approximately six weeks after plant emergence. Already by stage V12 the potential number of ovule and kernel rows is established since the ovule formation is complete and apparent on almost the entire ear length (O'Keefe, 2009). The commencement of stage V14 occurs about seven weeks after plant emergence. This stage is followed by V15 when the plant is 12-15 days away from the beginning of reproductive growth stage R1 which is silking. This is the most critical vegetative stage for the determination of kernel yield (O'Keefe, 2009). The determination of ovule number that develops silks and in turn the number of kernels occurs at stage V15. Injuries caused by insects and hail as well as any deficiencies at this stage may cause serious reduction in the number of kernels that develops. Although the tassel is not visible from the top of the leaf sheath, it is nearing its full size at this stage (O'Keefe, 2009). The upper ears begin to form silks. There is now development of brace roots from the sixth leaf node. The node at which the brace roots forms is specific with different hybrids. Eventually, the permanent root reaches about 100 cm in depth and spreads in all directions after its continuous elongation and proliferation (O'Keefe, 2009).

Late vegetative stage is reached by the plant approximately eight weeks after emergence as stages V16-V17. By V17 the hybrids that have more than 16 leaves will have the ear shoots tips visible at the leaf sheath top and the tassel may be visible. At VT which is the transition stage from vegetative to reproductive stage, the plant reaches its full size in prolific-leafing hybrids (O'Keefe, 2009). The tassel that forms at this stage is a male flower of maize that is responsible for producing enough pollen for fertilization of the ovules in the female flower known as the ear. Approximately 2000-5000 million pollen grains are produced for each silk in the presence of 1000 silks per cob. The appearance of the tassel tip and the tip of the emerging ear normally occurs at about the same time (O'Keefe, 2009). This can generally be one or two days away from the first silk appearance. One week away from viable silking, the ear development is continuing rapidly. Larger grain yield reductions occur if there is environmental stress such as hail, high temperature, water stress and nutrient deficiency two weeks before or after silking (O'Keefe, 2009).

2.3.2 Reproductive development stages

There are three broad stages that chiefly characterize reproductive stage in maize and these are pollen formation, ovule fertilization and kernel formation. These stages in maize are expressed by stages R1-R6. Stage R1 is the pollen shedding and silking stage (O'Keefe, 2009). Typically, the emergence of silks occurs 1-3 days after pollen began shedding. During pollination the shedded viable pollen should land on receptive silks. This pollen should further germinate and there must be formation of pollen tubes that will allow fusion of male gametes with female gametes inside the ovule (O'Keefe, 2009). After fertilization process follows the kernel development (grain fill) which is the concluding stage of maize development ranging from flowering period to physiological maturity. This stage is accompanied by carbohydrate and protein deposition in the kernel as its growth progresses. This phase determines final yield and the conditions that the plant is exposed to at this stage affects grain quality critically (O'Keefe, 2009).

Kernel development in maize is represented by several stages from R2 to R6. The developing kernels go through the first stage at R2 which is blister stage that occurs ten days after fertilization. This stage is expressed as watery blisters on the cob (O'Keefe, 2009). Most of the physiological activity in maize is directed towards kernel filling during blister stage. The full length and diameter of the cob is reached by the time this stage initiates. Following blister stage is milk stage R3 which takes place approximately 20 days post pollination (O'Keefe, 2009). The outside of the kernels are now evidently yellow but filled with a milky almost fluid substance. This milky substance constitutes of great amount of sugars; and protein as well as starch forming bodies starts forming. Dough stage R4 then follows after blister stage when there is a continuation of sugar accumulation into the kernel endosperm, rapidly converted into starch (O'Keefe, 2009). According to du Plessis (2003), soft dough stage is when the conversion of sugars to starch take place and the grain mass continues to increase. At this stage approximately 55% of the kernels initiates dents. Whereas, more than 90% kernels dents at hard dough stage that is characterized by a rapidly diminishing amount of sugars in the kernel. There is now an accumulation of starch in the kernel crown which extends downwards (du Plessis, 2003).

O’Keefe (2009) has pointed out that the first area that accumulates hardened, dry starch is the top of the kernel.

Dent stage R5 is reached 40 days post fertilization when the area across the kernel has a visible definite band which is denoted as the milk line. This is the line that lies between maturing dry starch and the milky deposits. The full size is almost reached in the embryo by the seventh week into kernel development O’Keefe (2009). Moreover, by this time there is a slowdown of the filling in the kernel and maturity is approaching. The final stage of maize development is physiological maturity R6 which takes place by the end of eighth week post pollination (O’Keefe, 2009). During physiological maturity the maximum dry mass of the kernel has been reached and the moisture content is diminishing at this stage. There is also a development of black cells at the base of the kernel indicating that the kernel has reaches physiological maturity (du Plessis, 2003; O’Keefe, 2009). When 75% of the kernels in the equatorial area of the cob have black layer, then maturity on an individual ear can be declared. It takes about 50-60 days for physiological maturity to be reached after pollination (O’Keefe, 2009). The concluding stage of development in maize is biological or harvest maturity marked by the drying of kernels (du Plessis, 2003; O’Keefe, 2009). The rate of dry-down is dependent on weather conditions that a maize plant is subjected to at this stage. A grain moisture level that is favourable for harvesting should be reached at this stage the (O’Keefe, 2009).

2.4 Effect of hail damage on crop productivity

2.4.1 Crop responses to hail damage

Hail is defined as the precipitation type of irregular lumps of ice balls which are always produced by convective clouds (Changnon, 1977). This cumulonimbus clouds derived rainfall ranges between diameters of 5 mm to greater than 50 mm and is commonly accompanied by wind, lightning and rain showers. This phenomenon is related to the warm seasons of the year (Sisu *et al*., 2011). Peters *et al*. (2000) argued that this weather phenomenon occurs randomly and varies in intensity between miniscule to catastrophic intensity (Tollenaar and Daynard, 1978). Given that the occurrence of hail is unpredictable in terms of timing and magnitude where plants can be injured at any time, the mechanical damage experienced is the source of abiotic stress to plants (Tartachnyk and Blanke, 2002).

Hail poses risks to agriculture (Sisu *et al*., 2011). Maize, among other cereal crops, is extremely susceptible to hail injury, whereas, wheat is the most resistant (Lemons, 1942). There are many ways in which hail can injure plants. These include ruptured leaves, flowers and fruits depending on the stage of plant development during the damage. These injuries may enhance stand reduction (reduced plant density) and defoliation (Burmood, 1971; Schneiter and Johnson, 1994; Lauer *et al*., 2004; Robertson *et al*., 2011). It is, however, evident that only the exposed above ground parts seems to be damaged by hail in contrast to the below ground parts that are almost always left undamaged after hail storms (Lauer, 2009). In addition, Burmood (1971) has identified hail damaged crops with bruising, breakages, topping and shattering. These plant conditions after hail damage promotes premature plant death (Lauer, 1994), sterility and increases the susceptibility of crops to bacterial and fungal infection after hail damage, which consequently reduces grain yield (Robertson *et al*., 2011). The reduced yield response of crops from hail damage also hinders optimum plant growth. It was reported in a study conducted by Lauer *et al*. (2004) that up to 10% yield losses may be experienced due to hail induced defoliation. However, Lauer, (2009) reported that on the contrary, seed yields were not affected.

Generally, when it comes to yield reduction, there are three ways in which hail affects maize. These include reduction of plant stand, leaf defoliation and direct damage. Defoliation has the greatest effect on crops especially at pollination stage (Klein and Shapiro, 2011). Moreover, both the stand reduction and defoliation also have primary effect in causing great losses (Lauer, 2009). In addition, not only the plant organs are damaged by hail, but also physiological processes are frequently damaged by hail (Anda *et al*., 2002). Physiological maturity of maize is reached earlier than expected after the crop has been exposed to hail damage. However, it takes longer for such crops to dry down (Lauer, 2009). Maize growth may be retarded as a result of stress caused by hail injury (Lemons, 1942).

There are factors affecting the extent to which a crop is injured by hail. These factors may be grouped according to plant factors, hail factors environmental factors and management factors. Plant factors include nature and type of plant, physiological state, growth stage and leaf turgidity (Lemons, 1942; Schneiter and Johnson, 1994; Sanchez *et al*., 1996; Robertson *et al*., 2011). Hail factors pertains hail storm strength, velocity, hardness, duration and intensity as well as hail stone size (Lemons, 1942; Schneiter and Johnson, 1994; Sanchez *et al*. 1996; Bore *et al*., 2011). With regards to hail stone size and diameter, it was reported by Bore *et al*. (2011) that the smaller the diameter and size, the greater the damage and losses experienced. The environmental and management factors include weather conditions and production practices, respectively (Burmood, 1971; Klein and Shapiro, 2011).

According to a study by Burmood (1971), soybean varieties showed a variation in response to hail damage. In addition to genotype response, it was argued that plants at different growth stages respond differently to hail damage. Damage occurring in the earlier plant stages is usually less severe with the exception of when the storms are very destructive. However, susceptibility to hail damage is great near maturity stages (Lemons, 1942). This was confirmed by Burmood (1971), who established that yield reductions were greater with the advancement of plant development stage. It was reported that hail induces highest yield losses when inflicted at reproductive stages of crops (Burmood, 1971). It was reported that stand reduction to hail damage at early stage of crop development had less effect on plant performance and maturity processes. Moreover, the plants attain less lodging when the stems are hail damaged at early stages of development since the plants are shorter and less susceptible to lodging at that point (Burmood, 1971). Plant deaths are highest when physical injury is imposed at transition stage from vegetative to reproductive stage of development. The extent of plant damage is additionally influenced by plant status of leaf turgidity at the time of the storm (Schneiter and Johnson, 1994) particularly when the damage is imposed on the foliage.

The afore mentioned factors that affect crop response to hail damage also affect the compensatory process of crops after hail damage. In addition to the type of variety that determines the compensatory process after hail damage is the factor of weather. Weather conditions immediately after hail injury have profound effects on a crop's eventual recovery. Rapid rejuvenation may be encouraged by favourable weather, whereas, unfavourable weather commonly encourage insects and diseases which may retard growth and maturity (Lemons, 1942). The compensation process is also dependent on the stage of growth when hail damage is experienced. The recovery process diminishes with the advancement of growth stage (Schneiter *et al.*, 1987; Johnson, 2003). This is caused by the diminished time remaining for plants in the field during its growing season, for them to undergo the process of compensation (Schneiter and Johnson, 1994). It was observed after plants were damaged at stage V6 that they were able to recover. However, no plant recovery was evident when plants were damaged at V8 stage (Pearsoni and Fletcher, 2009). The amount of regeneration and suberization is also dependent on the amount of damage incurred (Anda *et al*., 2002). The process of regeneration, if any, may be inadequate if the injury is severe than when there is a minor injury. Replanting may not be necessary if the compensation and crop rejuvenation was efficient after the crops were damaged by hail.

2.4.2 Defoliation and leaf area loss

There are many factors that promote defoliation in plant production. These factors include natural causes such as insects, diseases, hailstorms and wind; as well as unnatural causes such as herbicides that are administered incorrectly and farm machinery damage to crops (Erbas and Baydar, 2007). However, for the purposes of this study hailstorm induced defoliation is emphasized. This defoliation phenomenon in plants is affected by many factors such as weather and environmental conditions under which the crop is grown as well as the nature and status of the crop (Lauer *et al*., 2004). These factors determine the extent to which the economic performance of crops is affected. Crop maturity may be delayed with the consequence of stunted growth that may also reduce plant stand (Kalton *et al*., 1949; Burmood, 1971).

Defoliation significantly affects crop maturity, leaf area index (LAI), chlorophyll content and harvest index (HI) as well as seed number (Alimohammadi and Azizov, 2011). Not only does defoliation and decreased leaf area reduce seed yield but also seed mass, oil yield and percentage (Kalton *et al*., 1949; Gazzoni and Moscardi, 1998; Erbas and Baydar, 2007). Loss of yield after hail damage is as a result of loss of photosynthetically active leaf area (Bartolo *et al*., 1994). This loss is dependent on the amount of leaf area loss and growth stage. Leaf area loss results in loss of the plant's ability to produce dry matter thus reduced yield through limitations on photosynthesis (Bartolo *et al*., 1994). Schneiter *et al*. (1987) argued that seed yield was also decreased as a result of loss of photosynthesis and a reduction of photosynthetic material. In terms of losses with respect to growth stage, it was reported by Burmood (1971) that the deleterious effects of hail on the aspects of plant performance are amplified at the reproductive stage as opposed to when the damage is imposed at the vegetative stage. According to Kalton *et al*. (1949), crop maturity was delayed when defoliation was imposed during vegetative stage and hastened when imposed after flowering. Burmood (1971) further alluded that if the plants were damaged or cut off below the cotyledons, plant stand would be reduced due to the removal of axillary buds; hence, the plant becomes unable to produce new branches and dies off.

According to Bartolo *et al*. (1994), not only is the marketable yield reduced by defoliation but also marketable quality of agricultural crops. Marketable equality is compromised by a prevalence of diseases on defoliated plants as opposed to non-defoliated plants. Leaf area loss also predisposes plants to pathogen infections. In addition, defoliation induced disease infestations on produce quality may also perpetuate quality reduction during storage which affect subsequent crop productivity and marketability (Bartolo *et al*., 1994). Weeds are also encouraged by increased light penetration through the canopy and into the ground as a result of defoliation and leaf area loss. This is accompanied with reduced competition among plants for water and nutrients due to stand reduction and these resources may in turn be available to weeds (Schneiter and Johnson, 1994; Lauer, 2009). Weed pressure also affect plant performance as well as yield and seed quality as a result of stress conditions that they create through competition for resources.

Photosynthates for plant growth are supplied by leaves (Bartolo *et al*., 1994). In addition to being photosynthesizing organs, plant leaves are also transitory storage tissues where the photosynthates and absorbed nutrients primarily accumulate. These are later translocated to the seeds (Gazzoni and Moscardi, 1998). Hence the loss of leaf area equate to the loss of photosynthates to plant growth and other processes as a consequence of reduced photosynthesis (Robertson *et al*., 2011). However, stem, cob, shank and husk usually have temporarily stored soluble carbohydrates that can serve as assimilates source for kernel growth when there is a decline in photosynthesis at early grain filling stage (Tollenaar and Daynard, 1978). It was postulated in the previous study that hail mechanical injury induces stomatal closure, among other things, which might be responsible for reduced photosynthetic activity due to the lack of gaseous exchange (CO_2 and H_2O) and reduced transpiration. This particular study also reported that simulated hail damage through rupturing can cause the net overall loss of leaf area of 10 mm^2 (Tartachnyk and Blanke, 2002).

2.5 Seed quality

2.5.1 Seed quality and vigour

Seed quality is one of seed properties that is attributed by genetic quality, physical purity, physiological, seed health (disease status), viability, vigour and moisture content (George, 1999; Kerr, 2009; Bishaw *et al*., 2012). Seed colour, shape, size, thousand kernel mass and protein content are also indicators of seed quality (Kerr, 2009). Cultivar purity or varietal purity is important as an indicator of genetic quality in seed lots. Not only is genetic quality important in seed quality determination but also physical purity which characterises the absence or presence of contaminants and foreign matter in a seed lot. The presence or absence of seed-borne pathogens or pests is also an important attribute of seed health which plays an important role in seed quality characterisation (George, 1999). Genetics determines the seed quality components which are also influenced by environmental conditions during seed development on the mother plant, harvesting, processing and storage (Adebisi and Ojo, 2001). Therefore, it is evident that seed quality is affected by genotype by environment interaction. Additionally, according to Milosevic and Malesevic (2004), successful seed production development of a nation is dependent on climatic, environmental conditions and traditions.

High quality seed is very essential to the farmer for production of rapid, uniform and high yielding plants under a wide range of field conditions (Elias, 2006). The seeds of high quality are able to withstand unfavourable growing conditions, ensure good seedling stand establishment and optimum plant population (Penaloza *et al*., 2005; Elias, 2006). This performance by high quality seeds is firstly stimulated by superior and faster germination under a wide range of field conditions with maximal yields as compared to low quality seeds (Elias, 2006). Poor seed quality gives rise to problems of failing to establish vigorous maize seedlings. Whereas, high quality seeds are able to produce seedlings of high vigour across a wide range of environments (Adebisi and Ojo, 2001).

One of the vital components of seed quality is seed vigour (Duurant and Gummerson, 1990) which is defined as the sum total of seed properties that regulate both the activity level and performance potential of the seed or seed lot during germination and seedling emergence (Perry, 1980). Seed vigour as a complex physiological trait is required to ensure that the emergence of plants in the field is rapid and uniform under diverse environmental conditions (Ventura *et al*., 2012). Environmental conditions during seed development, genetic constitution, and storage are the three major factors that define the level of seed vigour. In addition, soil water, soil nutrition, relative humidity, temperature, oxygen content, harvest stage (maturity), as well as ageing, mechanical damage during harvest, storage time, seed size, mass and plant pathogens could modify the seed vigour level which is specific with seed type. This seed trait increases with time and maturity on the parent plant (Sun *et al*., 2007; Milosevic *et al*., 2010).

High quality seeds are very vital to farmers and growers since they enhance uniform field establishment and increased plant production (Ventura *et al*., 2012). The activity and behaviour of the commercially acceptable seed lots in different environmental conditions is manifested by a set of seed viability or seed vigour characteristics (Milosevic *et al*., 2010). High vigour seeds also exhibit the presence of uniform and rapid germination; and growth of more resistant seedlings which consequently enhance better field performance and higher yield. The opposite is the case in low-vigour seeds that are characterized by much unsatisfactory performance (Sun *et al*., 2007). The effect of seed vigour is very important on useful value and storage longevity of seeds (Sun *et al*., 2007; Milosevic *et al*., 2010).

Seed quality may be demonstrated by standard germination test which is usually employed for the prediction of field emergence under nearly ideal soil conditions (Duurant and Gummerson, 1990). These tests are necessitated by the prerequisite of successful seed germination for plant development and agricultural production (Ventura *et al*., 2012). However, it is very important to test seed viability using different seed vigour tests since the results of these tests frequently have better correlation with the field germination results under unfavourable environmental conditions. This is contrasting with the standard laboratory germination test results that rarely correlate with field performance of crops (Johansen and Wax, 1978; Penaloza *et al*., 2005). Despite the fact that standard germination test is conducted under ideal laboratory conditions that are seldom in the field, the test still remains the most common measure of seed quality for various crops (Penaloza *et al*., 2005). According to Penaloza *et al*. (2005) the results of seed vigour tests for potential seed lot behaviour should permit objective, rapid and accurate assessment of seed quality. Milosevic and Zlokolica (1996) argued that seed vigour test results were vital in the decision making of sowing dates. These decisions may be whether to sow the seed lots earlier in the season with the possibility of stressful conditions occurring, or later sowing date when the soil is warmer with more favourable soil conditions for germination and seedling growth (Milosevic and Zlokolica, 1996).

According to McDonald (1975) there are three groups of vigour tests, and these are; physical, physiological and biochemical tests. Physical tests are employed to determine seed size and mass characteristics. These tests have an advantage of being inexpensive, quick and applicable to large number of samples. Moreover, these tests have a positive correlation with seed vigour. The importance of the test is emphasised by the fact that vigour traits such as size and mass of seed are directly correlated with the nutritive materials accumulation as the main feature of seed development (McDonald, 1975). The employment of germination and growth parameters is carried out in physiological tests. Physiological tests are divided into two types such as when germination is carried out under favourable and unfavourable conditions. Under favourable conditions standard laboratory germination and growth intensity tests are adopted. Whereas the seed is exposed to unfavourable environmental conditions in cold test, accelerated ageing test and Hiltner test. Moreover, the estimation of seed value using an indirect technique is carried out in biochemical tests such as Tetrazolium test, enzyme activity, conductometric measurements, and respiration test (McDonald, 1975).

It is important to ensure high seed quality in modern seed science since the foundation of each plant production is exhibited by seed. Moreover, high seed quality is a prerequisite for attaining high plant yields of all species. The marketability of seed lots is indicated by determination of seed quality as well as viability. Therefore, for seed quality and seed vigour testing it is very vital to have reliable methods and tests adopted. Vigour in seeds amplifies the physiological traits of seeds that govern their ability to promptly germinate in the soil. This seed quality attribute also enables the endurance of different negative environmental factors by the seeds (Milosevic *et al*., 2010).

2.5.2 The acquisition of seed quality

According to O'Keefe and Schipp (2009) and du Plessis (2013) and, the constituents of maize kernel are a pericarp, the starchy endosperm, embryo and tip cap. All the parts that contribute to the next generation are found in the embryo. The endosperm which forms the bulk part of the seed, when mature, has regions that contain complex carbohydrates (~80%), oils (~20%) and minerals (~25 %) (du Plessis, 2003; Dolfini *et al*., 2007). Until the roots and leaves are well established, the endosperm provides the young plant with the energy (O'Keefe and Schipp, 2009). The embryo in the kernel contains approximately 80% fats, 75% minerals and 20% proteins (du Plessis, 2003; Dolfini *et al*., 2007). The parts that are contained by the embryo will develop first in a new seedling and these are the growing point, the initial root and the first 5-6 leaves (O'Keefe and Schipp, 2009). The entire kernel is enclosed and protected by the pericarp and tip cap (O'Keefe and Schipp, 2009; du Plessis, 2013).

The acquisition of all these seed parts through to development and subsequent seed quality is subject to many factors. These factors include pests, diseases, mechanical damages and hail that remove the foliar. The result of these constraints is a decrease in photoassimilate translocation to the kernels which consequently decreases seed yield (Alimohammadi and Azizov, 2011; Siahkouhian, 2012). Leaf parts that may be removed by these constraints are vital for photosynthetic activity essential for seed filling. The flowering and seed filling stages are the most sensitive periods to leaf area loss. Consequently the seed quality components become compromised by constraints at this stage (Alimohammadi and Azizov, 2011). There is a general notion that favourable conditions to high yields are also favourable to acquire seeds of high quality during seed production (Muasya *et al* 2008). A study by Muasya *et al*. (2008) agreed with this notion when inferior seed quality was attained under production conditions that promoted low yields or seed mass quality.

Sexual reproduction is a vital process in maize for seed development that takes place shortly after silking. Shortly after silking stage in maize, a new individual (seed) is formed after male and female gametes have fused during the process of fertilization. This process is manifest by double fertilization of the ovule by the pollen grain, after which the seed is formed, containing both the storage tissue (endosperm) and the zygotic embryo within the ovary (Salvador, 1988; Ventura *et al*., 2012). The inhibition of embryo growth, accumulation of storage products and the acquisition of desiccation tolerance mark the beginning of seed maturation (Ventura *et al*., 2012). With maturity, seeds accumulate more starch and proteins together with a decrease in moisture content. During seed maturation there are regulatory networks responsible for integrating genetic programs, metabolic signalling and hormonal signaling pathways which in turn induce dormancy that allows seed survival in the environment (Ventura *et al*., 2012).

The processes leading to seed acquisition begins when all leaves are unfolded completely and the visibility of the tassel is obvious. This is when the main ear bearing lateral shoot and the bracts are mature and accompanied by high water and nutrients demand. This stage is considered to be a green mealie stage where the accumulation of starch in the endosperm initiates. Following this stage is soft dough stage which is characterized by continued increase in grain mass coupled with conversion of sugars into starch. The sugars in the kernel then diminish quickly at the hard dough stage. Whereas, the accumulation of starch in the crown of the kernel further extends downwards (du Plessis, 2013). The product of the duration and rate of starch accumulation results in the final kernel mass (Jenner, 1986). Physiological maturity that follows is a stage around which maximum seed quality of field crops is attained which is at the end of seed filling period (Muasya *et al* 2008; Ghassemi-Golezani *et al*., 2011; du Plessis, 2013) when there is maximum seed dry mass and a layer of black cells develops at the kernel base (Muasya *et al* 2008; du Plessis, 2013). Thereafter, there is a prerequisite for physiologically matured grains to only reduce the moisture content within the kernels. This event precedes biological maturity which is marked by seed drying stage. The process of drying occurs at roughly 5% per week, up to 20% moisture level when conditions are favourable. Subsequently, there is a slowdown in the drying down process of seeds (du Plessis, 2013). Before harvest maize moisture content should have decreased significantly.

2.5.3 Effect of hail damage on seed quality

The issue of whether the subsequent seed quality is affected by simulated or natural hail damage is controversial. Some authors are for the affirmative and others are against the notion. According to some authors, seed quality and quality aspects such as seed yield, seed size, seed mass, germination, 1000 grain mass, kernel moisture content, protein content, oil content and starch content were affected by the consequences of hail damage, mostly deleteriously. Seed quality of major crops is affected by weather conditions. Variable weather conditions before and during seed formation may induce poor seed quality which in turn can impede subsequent crop production (Muasya *et al*, 2008). Burmood (1971) and Vasilas and Seif (1986) reported that decreased kernel yield and size as well as reduced seed quality were associated with induced defoliation. Hail induced defoliation reduces the supply of photosynthates and subsequently results in asynchronization of pollen shedding and silking, hence decrease maize yields (Vasilas and Seif, 1986). The loss of yield, particularly seed yield is the consequence of lack of fertilization. However, if fertilization was successful, Singh and Nair (1975) argued that a reduction in the sucrose supply to the developing seeds due to defoliation was the cause of kernel size reduction.

Robertson *et al*. (2011) further alluded that there was a detrimental effect caused by hail damage on the grain quality of maize. Germination rate was reduced by complete defoliation as a result of kernel size reduction. The reduction in seed germination due to complete defoliation was established in the warm and cold test which was 28% and 41% decrease, respectively (Vasilas and Seif, 1986). Furthermore, leaf area loss also resulted in a decrease of 1000 grain mass in addition to reduced number of seeds (Muro *et al.*, 2001). In addition, hail damaged grains had the lowest test mass, starch content, oil content, and seed mass, whereas, the protein content was higher. It was then concluded that hail damage had a detrimental effect on grain oil, protein, starch content and seed mass (Robertson *et al.*, 2011). All these detriments are caused by impairment of photosynthesis due to leaf area loss which translates to less assimilate. The result is also a deficit in photosynthates transported to the seeds for development and the acquisition of seed quality. The development of other plant parts also experiences a deficit in the supply of photosynthates to promote plant development and survival. On the other hand, Tollenaar and Daynard (1978) reported that kernel moisture content was significantly affected by defoliation treatments.

On the contrary, some authors found that hail damage had no effect on seed quality and seed quality components. According to Siahkouhian (2012) findings, there were no significant effects of defoliation treatments on protein, oil and seed moisture. In one season of their experiments there were no effects of complete defoliation on the entirety of seed quality (Vasilas and Seif, 1986). These findings were congruent with those where there were also no significant differences in hail damage response between grains from hail damaged and non-hail damaged treatments (Robertson *et al.*, 2011). Kalton *et al.* (1949) also reported that the seed quality component such as protein percentage was not affected by defoliation treatments.

Despite the controversies and contradictions about seed quality response to hail damage, the extent to which seed quality is affected by hail damage is determined by many factors (Muasya *et al*, 2008). Genotype, growing conditions, plant growth stage and the level of defoliation are among those factors (Vasilas and Seif, 1985b). It is these afore mentioned factors that may have caused controversial and sometimes contradictory results in terms of seed quality response to hail damage. This highlights the importance of conducting more research with the emphasis of using different cultivars and different environmental conditions for growing. This also implies that there should be specific levels of simulated hail damage at different plant stages during field trials. These should be considered in attempting to bridge the gap in research that yields contradictory findings.

With the concern of plant growth stage during hail storm, some authors have reported different responses of seed quality when hail was experienced at different plant growth stages

(Lauer, 2009; Pearsoni and Fletcher, 2009). According to a study by Lauer (2009), hail damage has detrimental effect on grain yield when experienced at kernel grain fill compared to other plant growth stages. Conversely, Pearsoni and Fletcher (2009) argued that the differences were not statistically significant in terms of grain yield between the defoliation treatments at different plant growth stages. Contrary to grain yield, this author reported that there were differences in grain moisture content with respect to growth stage. At V4 stage treatment, grain moisture content was greater than the V2 treatment and the control (no defoliation) (Pearsoni and Fletcher, 2009). These previous studies have indicated the importance of inflicting simulated hail damage at different plant growth stages.

2.6 Significance of plant density on maize growth and yield

Plant density considerably affects maize more than other members of the Poaceae family (Vega *et al*., 2001). Plant density, which is inter- and intra-row spacing, determines the plant's spatial distribution, canopy structure, and solar radiation interception (Mattera *et al*., 2013). This will subsequently affect photosynthesis and yield (Stewart *et al*., 2003). Sangakkara *et al*. (2004) and Mattera *et al*. (2013) argued that even under optimal growth conditions most parameters of the maize plant are affected by spatial arrangements. Different spatial arrangements have an effect on resource competition between plants (Sangakkara *et al*., 2004; Mattera *et al*., 2013). Plants in the same area usually compete among each other for resources necessary for growth and development. These resources include space, water, nutrients and solar radiation (Duncan, 1984; Sangoi, 2001; Sangakkara *et al*., 2004; Zamir *et al*., 2011; Shafi *et al*., 2012).

Spatial distribution of plants within the canopy and consequently plant density have an effect on intercepted photosynthetically active radiation (PAR) which in turn affects photosynthesis and yield (Chim *et al*., 2014). However, contradicting results were also reported by Johnson (2003) whose findings showed that population density had no significant effect on maize yield. With respect to plant traits, previous studies have indicated that maize plant characteristics such as leaf area index (LAI) and plant height were significantly affected by plant density (Valadabadi and Farahani, 2010; Abuzar *et al*., 2011; Shafi *et al*., 2012; Mattera *et al*., 2013; Chim *et al*., 2014). Among other important cultural practices, optimum plant density per unit area is a prerequisite that can enhance maximum crop production (Sangoai, 2001; Gustavo et al., 2006). Valadabadi and Farahani (2010) reported that leaf area index (LAI) increased with an increase in plant population as a result of increased photosynthesis which increased with leaf development. This was attributed to the fact that under high plant density plants are able to take spatial advantage and efficiently utilize the resources necessary for photosynthesis as opposed to low plant density (Burmood, 1971; de Bruin and Pedersen, 2008; Shafi *et al*., 2012). However, there is a limit to the benefits provided by increasing plant density i.e. a point of diminishing marginal returns. This is related to a series of consequences that are detrimental to plant yield results when the number of plants per unit area is increased beyond the optimum plant density (Sangoai, 2001).

Contrary to LAI response, high plant density has a negative effect on plant height. It was reported that plant height decreased under high plant density as a result of crowding and high competition for resources (Sangakkara *et al*., 2004). Low plant density promotes less competition pressure, therefore, abundance of available resources for plant growth and development (Abuzar *et al*., 2011; Zamir *et al*., 2011). These available resources may be efficiently utilized by fewer plants in an area (Zamir *et al*., 2011). On the other hand, while low plant population may be favourable due to less intra-species competition, less than optimum plant populations have a deleterious effect on crop yield (Nasir, 2000). This therefore justifies the need for optimum plant density that allows for yield maximisation.

In addition to the effect of plant density on canopy structure is the subsequent response of plant yield. Solar radiation interception has an influence on photosynthetic capacity of plants, vegetative and reproductive partitioning and final yield of various plants (Zamir *et al*., 2011; Shafi *et al*., 2012). Yield factors in maize that are affected by plant density are harvest index (HI), biomass as well as cob and seed production. The cob parameters that are significantly affected by plant density during crop production are cob number, mass, length, seed row and seed number per cob. Furthermore, seed mass is also influenced by plant density (Sangoi, 2001; Zamir *et al*., 2011; Shafi *et al*., 2012; Mattera *et al*., 2013; Farnia and Mansouri, 2014).

Harvest index and grain yield were shown to increase under high plant density as opposed to low plant density (Burmood, 1971; Duncan, 1984; Shafi *et al*., 2012; Chim *et al*., 2014). However, grain mass is deleteriously affected by high plant density. This is enhanced by high resource competition, hence less available photosynthates for grain development under high plant density (McGregor, 1987). The studies whose conclusions showed no significant yield advantage in narrowing inter-plant spacing (high plant density) indicated that the consequences of high population density in most plants were stunted plants, small ear size, and high susceptibility of crops to lodging, pests and diseases (Cardwell, 1982; Duncan, 1984; Sangoi, 2001). Furthermore, ear prolificacy, cob length and mass, grain yield and mass can also be affected deleteriously by high planting density (Sangoi, 2001; Zamir *et al*., 2011; Shafi *et al*., 2012).

The review of literature in this study confirmed that there is a limit to the benefits of increasing plant density. In theory, there is a positive linear relationship whereby any additional plants will result in additional yield attained, up to a certain point. As previously alluded to, while low plant populations may be ideal, they can also result in less resource use efficiency. Therefore, lower plant populations may be ideal in environments where resources are limiting while high populations can be ideal under optimum conditions, e.g. for maize we use 26 666 plants /ha under rainfed conditions but can go up to 40 000/ha under irrigated conditions.

2.7 Conclusion

Maize is a major staple for many regions of the world particularly the third world, where it plays an important role in food security as a source of calories. With increasing global food demand, maize continues to play a prominent role in ensuring food supply for the increasing world population. Not only does the crop contribute to food and nutritional security, it also provides economic livelihoods to farmers and the industry. With most research efforts being focused on the development of high yielding varieties, the effect of the reality of global climate change with respect to increasing weather extremes such as hail and the resulting damage to crops has attracted limited attention. Although there are significant economic losses incurred due to hail in agricultural production, limited efforts have been dedicated to understanding and mitigating the phenomenon through good crop management.

In addition to direct damages incurred to crops through hail damage, there is a lack of clarity in terms of whether seed quality is affected by hail. Hail damage has socio-economic importance since it results in fewer returns for the farmer due to reduced yields. Not only does hail have deleterious effects on crop yield it may also affects seed quality. The economy of farmers is affected by destruction in the fields from hail which may produce crops with suboptimal seed quality and in turn lower yields especially in cases where farmers retain their own seeds for the successive season.

While the agronomic aspects of hail damage have been studied in other parts of the world, especially in the developed world, the review of literature for this study did not identify reports on the effect of hail damage on subsequent maize seed quality. This highlighted a research gap that exists in seed science, particularly in southern Africa. In addition to understanding the general effect of hail damage on maize, information about the genotype x environment interaction will be derived by using three cultivars and three sites. Also, the interactive effects of timing of hail damage and agronomic management in the context of plant density will be determined. Consequently, the outcomes of this study will be useful for general maize agronomy and the seed industry associated with the crop.

CHAPTER 3

MATERIALS AND METHODS

3.1 Plant material

Seeds of three maize cultivars [Zama Star (ZS), SC701 and Mac Medium Pearl (MMP)] were used in this study. Zama Star seeds were purchased from Starke Ayres, South Africa, whereas Mac Medium Pearl and SC701 were purchased from McDonald's Seeds (Pietermaritzburg, South Africa). Zama star is a multipurpose white mealie maize cultivar that takes about 90-95 days to mature. Mac-Medium Pearl is multipurpose maize cultivar that takes approximately 75 days to maturity. SC701 is a green mealie maize cultivar that takes approximately 150 days to physiological maturity.

3.2 Seed quality tests

In order to establish and assess seed quality of the three maize cultivars, several established seed tests were conducted at the University of KwaZulu–Natal's Seed Technology Lab. The seed tests included the tetrazolium test, standard germination test and electrolyte conductivity tests.

3.2.1 Tetrazolium test

The tetrazolium test was conducted under lab conditions. A completely randomised design with three replications of 10 seeds for each cultivar (Zama Star, SC 701 and Mac Medium Pearl) was used for this test. The seeds were soaked in petri dishes with distilled water for 24 hours to ensure easy dissecting. The seeds were then dissected longitudinally through the middle of the embryonic axis. After dissecting the seeds were soaked in 1% Tetrazolium staining solution. The petri dish was covered with the lid and kept at room temperature for 24 hours. Seed viability was then assessed after 24 hours by rating the red stained seed embryos as viable and the non-stained as non-viable seeds (ISTA, 2012).

3.2.2 Standard germination test

Standard germination tests were conducted under lab conditions according to ISTA (2012). A completely randomised design was used for the tests. 25 randomly selected seeds for each cultivar (Zama Star, SC 701 and Mac Medium Pearl) were germinated between brown paper towels. The seeds were placed equidistantly on two moist germination paper towels. After placing the seeds on the paper towels, another set of two moist paper towels were used to cover the seeds. The paper towels were then rolled and fastened with elastic bands on opposite ends and then sealed in zip-lock bags. The zip-locks were incubated under illumination in a germination chamber set at 20/30ºC (16/8 hours) for seven days. Germination was rated daily according to those seeds with at least 2 mm radicle protrusion until day seven.

3.2.2.1 Germination vigour indices

On day seven, fresh seedlings were randomly selected from each treatment for determination of seedling length, shoot length, root length, root: shoot ratio, fresh mass and dry mass. The lengths were measured using a ruler. Fresh mass was determined using a digital sensitive balance (Masskot, FX320, Switzerland). The seeds were then dried in an oven (70ºC for 72 hours) in order to determine dry mass.

3.2.2.1.1 Mean Germination Time (MGT)

Mean germination time (MGT) was calculated as per Ellis and Roberts' (1981) equation:

$$\mathbf{MGT} = \frac{\mathbf{\Sigma\, D\, n}}{\mathbf{\Sigma\, n}} \qquad \textbf{Equation 3.1}$$

where: D is the number of days from the beginning of germination, and

n is the number of seeds that have germinated on day D

3.2.2.1.2 Germination Vigour Index (GVI)

Germination velocity index was calculated according to Maguire's (1962) formulae:

$$\mathbf{GVI = G1/N1 + G2/N2 + \ldots + Gn/Nn} \qquad \textbf{Equation 3.2}$$

where: GVI = germination velocity index,

G1, G2…Gn = number of germinated seeds in first, second… last count, and

N1, N2…Nn = number of sowing days at the first, second… last count.

3.2.3 Electrolyte conductivity

The analysis of seed electrolyte conductivity (EC) was carried out in the lab as per ISTA (2012) guidelines, with some amendments. A completely randomised design with three replicates of 30 seeds for each cultivar (Zama Star, SC701 and Mac Medium Pearl) was used. The seeds were weighed individually using a digital sensitive balance (Masskot, FX320, Switzerland) and expressed in grams (g). The CM 100-2 conductivity meter (Reid and Associates CC, South Africa) whose conductivity cells were cleaned and rinsed with distilled water before the test was used to measure EC. The CM 100-2 conductivity meter machine was initially calibrated using distilled water prior to testing the seeds. Individual seeds were placed into individual wells (2 ml); the wells were then filled with 2 ml of distilled water. Thereafter, electrolyte conductivity was recorded over 24 hours and reported as µS/ g/ hr.

3.3 Field trials

A set of field trials was conducted to determine the effect of simulated hail damage on growth, development, yield and subsequent seed quality of the three maize cultivars. The field trials were conducted at three different locations.

3.3.1 Description of experimental sites

The field trials for hail damage simulation were conducted at two sites in the province of KwaZulu-Natal (KZN), South Africa under rainfed conditions. These sites, Baynesfield (Bay) and Swayimane (Swa), are situated in the Midlands of the province. The planting dates for Baynesfield and Swayimane were 20 and 17 November 2014, respectively. The trials were harvested in 2015 on 6 May and 29 April, respectively. Table 3.1 below shows the data on soils and climates for the two study sites. Figure 3.1 below shows the weather data of the sites before and during plant growth and development in the field.

Table 3.1: Soil and climate descriptions of the study sites (Baynesfield and Swayimane). *Note: Soil descriptions are based on the Soil Classification- a Taxonomic System for South Africa.

	Baynesfield (Bay)	Swayimane (Swa)
Geographical location	29° 46’ S; 30° 21’ E	29°42’ S; 30°57’ E
Altitude (m a.s.l.)	838	880
Bio-resource group	Moist Midlands Mistbelt	Moist midlands mist belt
Annual rainfall	800-1000 mm	900-1200 mm
Average temperature	17ºC	20ºC
Frost occurrence	Moderate to severe	Light and occasional
Soil texture class	Clay	Clay Loam
Clay content	>60%	24%
***Soil type**	Inanda Mayfield	Kranskop Dargle

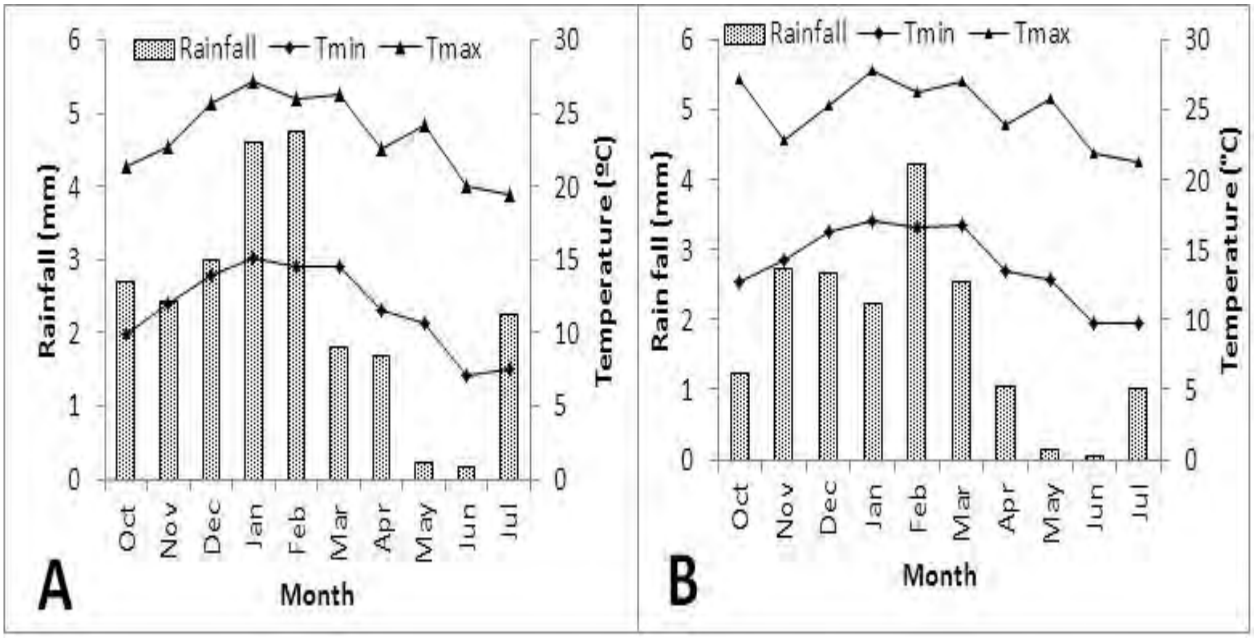

Figure 3.1: Climatic data for the cropping year from October 2014 to July 2015 for the study sites Swayimane (A) and Baynesfield (B).

3.3.2 Experimental design

The experimental design was a factorial experiment laid out in a randomised complete block design (RCBD), replicated three times. The factors were three cultivars ([Zama Star (ZS), SC 701 and Mac Medium Pearl (MMP), three plant densities [High (65 000 plants ha^{-1}), Moderate (46 000 plants ha^{-1}) and Low (28 000 plants ha^{-1})] and three simulated hail damages [control (no damage), V7 (damage at 9 weeks after planting)] and VT (damage at tasseling). Therefore, the treatment structure was 3 cultivars* 3 planting densities* 3 simulated hail damage*2 sites, replicated three times. Hail damage was simulated on maize plant leaves by stripping the entire leaves longitudinally four times into five sections through the entire length. The control treatments had no simulated hail damage.

3.3.3 Crop management

At all locations, ploughing was carried out in the field before planting. After ploughing, soil samples were taken and submitted for soil textural and fertility analyses. Based on results of soil fertility analyses (Table 3.2), 10 kg superphosphate fertiliser mixed with 5 kg LAN was broadcast in the whole planting area (20.2 x 20.2) m^2 at planting. The fertiliser was then incorporated into the soil using hand hoes. Four weeks after planting 25 kg LAN was applied as a top dressing. After applying the fertiliser, about 4 kg ha^{-1} stalk bore granules Carbaryl (Carbamate) were applied to plants to control stalk borer. Weeding was done routinely by hand-hoeing.

Table 3.2: Physical and chemical characteristics of soil at the different sites [Baynesfield, (Bay) and Swayimane (Swa)] used during the study (Department of Agriculture and Environmental Affairs; Soil Analytical Services, Pietermaritzburg).

Site	**pH (KCl)**	**Org. C**	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**
		(%)		**(mg/L)**						
Baynesfield (Bay)	4.12	3.3	0.20	8	121	543	276	1.4	13	7.2
Swayimane (Swa)	4.24	1.1	0.11	8	229	452	212	1.4	12	2.9

3.4 Data collection

3.4.1 Plant growth and physiology

The plants were given up to V7 stage before the non-destructive analysis of plant growth and physiology was carried out in the field. Four plants per plot were measured for plant growth and physiology parameters and averages were recorded. Plant height was measured from the ground level to the tip of flag leaf and tassel using a measuring tape. Leaf number was counted according to those leaves that had fully developed leaf collar that was visible. Leaf area index (LAI) and photosynthetically active radiation (PAR) were measured using the AccuPAR LP80 Ceptometer (Decagon Devices, USA). Stomatal conductance was determined using the Model SC–1 steady state leaf porometer (Decagon Devices, Inc., USA). A portable chlorophyll meter, the SPAD-502 Plus (Konica Minolta, Japan), was used to measure chlorophyll content index (CCI) from three fully expanded and solar radiation exposed leaves and averages.

3.4.2 Yield parameters

After harvesting, the trial maize cobs from four experimental plants were weighed with a digital sensitive balance (Masskot, FX320, Switzerland) and average mass (g) per plant was reported. Moreover, cob length (cm) of these four cobs was measured using a ruler and averaged. After shelling the crop, seed mass per plant as well as 1000 grain mass were weighed with a digital sensitive balance (Masskot, FX320, Switzerland). Thereafter, the seeds were categorised into Small (S) or Large (L) size. Seeds from each cob.

3.5 Effect of simulated hail damage on subsequent seed quality

The crop was harvested at physiological maturity to ensure that natural seed quality is not lost. After harvesting the trial the seed quality tests were conducted as described in section 3.2 for all the treatment combinations. The cobs were divided into two equal halves; upper (U) and bottom (B). All seed analyses were conducted using seeds from upper (U) part of the cob and bottom part (B) separately.

3.6 Crude protein analysis in seeds

Biochemical analysis of harvested seeds was conducted at the University of KwaZulu–Natal's Seed Technology Lab to determine proteins as per Bradford (1976). About 0.5 g DM of seed tissue powder was ground with electric blade grinder. The sample was extracted in 5 mL 50 mM Tris-HCl buffer (pH 7.4). The Bradford dye (1 mL) was added to test tubes with 20 µL sample extract which was mixed and incubated at room temperature for five min in 1 ml plastic cuvettes. The samples were read from the spectrophotometer (Shimadzu, North America) at 595 nm and the protein concentration was determined through the comparison of results with a standard curve (Appendix 1) constructed using bovine serum albumin.

3.7 Statistical Analyses

Data collected were subjected to analyses of variance (ANOVA) using GenStat® Version 16 (VSN International, United Kingdom) at the 5% probability level. Duncan's test in GenStat® at a probability level of 5% was used to compare means. Standard errors were also used to indicate statistical differences which were accepted at $P \leq 0.05$. Due to high CV values (>30%), LAI and PAR were transformed.

CHAPTER 4

SEED VIABILITY AND VIGOUR OF SLECTED MAIZE HYBRIDS

4.1 Introduction

Maize is produced throughout South Africa in various environments as the most important grain crop (du Plessis, 2003). Maize is among the world's leading crops utilized as a source of food, feed, fuel and fibre (Tenaillon and Charcosset, 2011). The success of the crop is determined by the production inputs among which are adapted cultivars. Different cultivars have different characteristics with varying adaptability and yield potential (du Plessis, 2003). The main reproductive strategy in flowering plants is seed production (Rajjou, 2012). Therefore, in addition to plant reproduction seeds are essential for dispersal of species to new locations. An important aspect of seeds is seed quality which contributes to plant development and agricultural production (Ventura *et al*., 2012). Seed quality is also vital for marketing of crops in the seed industry (Mattioni *et al*., 2015).

Cultivar or varietal purity is important as an indicator of genetic quality in seed lots. Not only is genetic quality important in seed quality determination but also physical purity which characterises the absence or presence of contaminants and foreign matter in a seed lot. The presence or absence of seed-borne pathogens or pests is also an important attribute of seed health which plays an important role in seed quality characterisation (George, 1999). Genetics determines the seed quality components which are also influenced by environmental conditions during seed development on the mother plant, harvesting, processing and storage (Adebisi and Ojo, 2001). Environmental factors that affect seed quality are water availability, soil chemical composition, ambient temperature, plant density, fertilisation, light and seed distribution on a plant, among others (Martinez-Villaluenga *et al*., 2010). It is therefore, evident that seed quality is affected by genotype by environment interaction.

High quality seeds are vital for the success of crop production. It was reported that these seeds produce high yields induced by high and rapid seedling emergence (Ghassemi-Golezani, 1992). Moreover, superiour seed quality also yields vigorous plants with optimum stand establishment under various environmental conditions (Ghassemi-Golezani, 1992). Therefore, high quality seeds are a prerequisite for uniform field establishment and high yields (Ventura *et al*., 2012). According to Ghassemi-Golezani (2010) and Ventura *et al*. (2012), optimum crop stand and high productivity are essentially promoted by rapid and uniform seed germination as well as subsequent seedling emergence. Hence, Mattioni *et al*. (2015) emphasised the importance of adopting fast and efficient methods of seed quality testing in order to ensure quality seeds. Therefore, proper evaluation and determination of seed quality aspects is vital to seedsmen and farmers in order to make informed decisions about the seeds they purchase (McDonald, 1975).

Seed quality may be represented by seed viability and vigour. Seed viability is the ability of seeds to germinate and emerge under optimum conditions. Viability tests such as germination and tetrazolium (TZ) tests are usually conducted under optimum conditions with the lack of consideration of adverse field factors. Viability tests can also indicate whether seeds are alive or dormant. (Sun *et al*., 2007). The optimum conditions are normally optimum moisture and temperatures that may not occur in the field (Elias *et al*., 2006). Even though viability tests provide crucial information on germinability, there are limitations to the test results. Viability tests do not factor in necessary information that is required about the seed lot's ability to establish under various and adverse field conditions. Therefore, significant problems for several important species may be posed by this limitation (Ventura *et al*., 2012). This necessitates analysis of seed vigour which is a more promising seed quality index reflecting potential seed germination, field emergence and seed storability under different conditions (Sun *et al*., 2007).

Seed vigour is not only dependent on the seed's ability to withstand prolonged storage but also the deleterious effects of aging. This signifies the importance of unfavourable field emergence conditions in determining whether seeds have low- or high-vigour (Ventura *et al*., 2012). Perry (1980) defined seed vigour as the sum total of all seed properties that regulate both the activity level and performance potential of a seed lot during germination and seedling emergence. Seed vigour is a complex physiological trait that is required for rapid and uniform field emergence of plants under a wide range of environmental conditions (Ventura *et al*., 2012). This ensures the production of normal seedlings (Hampton, 1995). The tests that can be employed to analyse seed vigour include electrolyte conductivity, cold test, accelerated ageing test and Hiltner test. Indirectly, seed vigour may also be analysed using TZ test, enzyme activity, conductometric measurements, and respiration tests (McDonald, 1975). Hence, seed vigour tests are important to seed analysts since the information from these tests aids in monitoring seed quality during production through to processing and storage (McDonald, 1975).

According to a study by Mazvimbakupa *et al*. (2014), there were high significant differences of maize seed vigour and viability characteristics among the varieties that were tested. McDonald (1975) reported that seeds with high vigour exhibited early field establishment which enhanced competitive advantages against weeds and microflora. This led to higher crop yields compared with low vigour seeds. Low vigour seeds may fail to germinate and establish into a mature plant as a result of endo-/ ectodormancy. Seed dormancy is the state in which seeds fail to germinate under suitable environmental conditions (Nasreen *et al*., 2002). This consequently results in poor stand and plant establishment as a common constraint faced by resource-poor farmers (Harris, 1996). There is still a research gap that should be addressed in an attempt to ensure that maize seed quality is adapted to environmental conditions to which the crop is grown.

It was hypothesised in this study that there are no differences between maize cultivars Zama Star (ZS), SC701 and Mac Medium Pearl (MMP) with respect to seed quality. Seed quality of the three maize cultivars was determined using a series of viability and vigour tests which included standard germination test, tetrazolium test and electrolyte conductivity.

4.2 Results and Discussion

4.2.1 Standard germination test

There were highly significant differences ($P < 0.001$) between cultivars with respect to standard germination rate over the seven day period as well as final germination percentage ($P = 0.002$). These results are consistent with reports in the literature (Aguilar-Benitez *et al*., 2014; Mazvimbakupa *et al*., 2015). Cultivar SC701 had the highest germination rate and consequently final germination percentage (100%), followed by ZS (98%) and MMP (94%), respectively (Figure 4.1). Results also showed that final germination percentage of SC701 and ZS was statistically similar. High seed germination may be attributed to seed factors such as adequate germination energy, mineral, protein, oil, hormone, and vitamin reserves (Salvador, 1988). This may mean that SC 701 had the abundance of all these elements followed by ZS as compared to MMP.

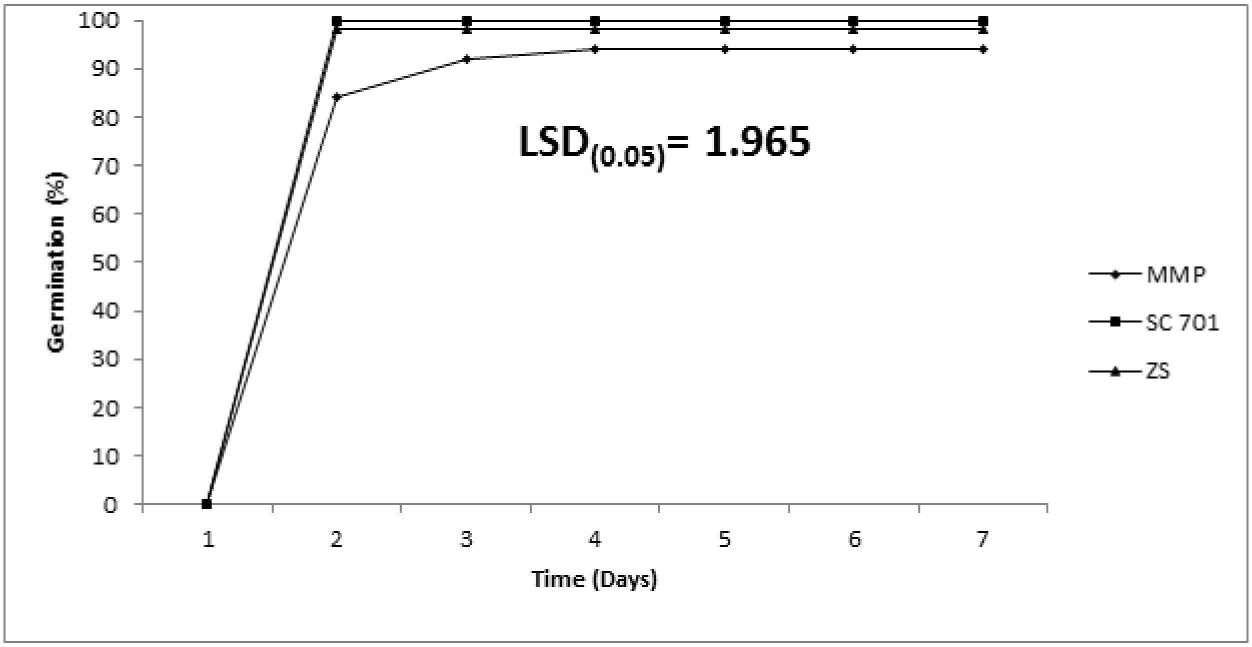

Figure 4.1: Daily germination percentage of maize cultivars Mac Medium Pearl (MMP), SC 701 and Zama Star (ZS) over seven day's period.

Table 4.1: Seed quality characteristics (viability and vigour) of maize cultivars Mac Medium Pearl (MMP), SC 701 and Zama Star (ZS).

	MC	**TZ**	**TGM**		**MGT**	**SL**	**RL**	**ShL**		**FM**	**DM**
Cultivar	**------%------**		**g**	**GVI**	**d**	**-------mm------**			**R:S**	**------g------**	
	15.1	100	365.0	36.02	4.55	164	44	120	0.36		0.24
MMP	c	a	a	a	b	b	a	b	a	1.52a	a
	13.4	96.8	373.6	39.82	4.50	129	45	84	0.53		0.20
SC 701	a	a	b	c	a	a	a	a	b	1.35a	a
	13.7	100	366.3	38.90	4.50	186	54	132	0.41		0.26
ZS	b	a	a	b	a	c	a	b	ab	1.28a	a
LSD	0.29	4.71	4.35	0.91	0.01	22.1	15.9	15.6	0.13	0.25	0.12
F.Pr	<.001	NS	.006	<.001	<.001	.002	NS	<.001	.049	NS	NS
CV (%)	1.2	2.8	0.7	1.4	0.2	8	19.3	8.1	17.7	10.5	29.9

NS= Not Significant, MC= Moisture Content, TZ= Tetrazolium, TGM= Thousand Grain Mass, GVI= Germination Vigour Index, MGT= Mean Germination Time, SL= Seedling Length, RL= Root Length, ShL= Shoot Length, R:S= Root:Shoot, FM= Fresh Mass, DM= Dry Mass

There were significant differences with respect to seed moisture content ($P < 0.001$), 1000 grain mass (TGM) ($P = 0.006$), shoot length ($P < 0.001$), seedling length ($P = 0.002$), germination vigour index ($P < 0.001$), mean germination time ($P < 0.001$) and seedling root: shoot ratio ($P = 0.049$) among cultivars (Table 4.1). These results are consistent with reports by Mazvimbakupa *et al*. (2015) who also reported GVI and MGT to have high significant differences ($P < 0.001$) among maize varieties. Tetrazolium test (% viability), root length, seedling fresh and dry mass showed no significant differences among cultivars (Table 4.1). However, Mazvimbakupa *et al*. (2015), observed significant differences while Mabhaudhi and Modi (2010) also reported no significant differences ($P > 0.05$) in root length, root:shoot ratio and dry mass of maize cultivars. It must be noted though that Mabhaudhi and Modi (2010) and Mazvimbakupa *et al.* (2015) were comparing hybrids and maize landraces while in the current study we only compared hybrids. Thus, the lack of significant differences among varieties may be confirmation of superior seed quality of hybrids.

Results of rate of germination and final germination percentage (Fig. 4.1) seemed to complement results of germination vigour index (GVI), mean germination time (MGT) and seedling root: shoot (R:S) ratio (Table 4.1). Similar to rate of germination and final germination percentage, it was evident that the order of superiority among the cultivars with respect to GVI, MGT and R:S ratio was MMP < ZS < SC 701. These vigour indices were contrasting to seedling dry mass since the superior cultivar (SC 701) had the least seedling dry mass meaning that it accumulated the least dry matter during the seven days of germination. There was no clear complementary relationship between the germination viability and vigour capacity of the cultivars and seed viability as manifested by tetrazolium (TZ) test.

The maize cultivar with the highest 1000 grain mass (SC701) showed higher germination capacity and viability compared to MMP which had the lowest 1000 grain mass. These results are in line with Batistella *et al*. (2002) who reported that contrary to small maize seeds, larger maize seeds exhibited higher germination and vigour. This was attributed to a positive correlation that exists between seed size and germination energy and capacity (Amin and Brinis, 2013; Aguilar-Benitez *et al*., 2014). There is a tendency for larger and heavier seeds to germinate earlier and quicker resulting in seedlings developing into larger plants accompanied by higher yields. Plump seeds contain more nutrient resources supporting germination and emergence of seedlings (Amin and Brinis, 2013). The influence of embryo size or mass could elucidate seed size and germination relationship since larger seeds generally possess larger embryos which promote increased germination (Lopez-Castaneda *et al*. 1996). Not only is the amount of food reserves in seeds reflected by grain size but also physiological biosysnthates that support germination and early seedling establishment growth (Msuya and Stefano, 2010). Therefore, 1000 grain mass as one of seed quality indicators is positively associated with seed quality in terms of germination and emergence. Protic *et al*. (2007) reported that seeds with higher 1000 grain mass also exhibited superiour germination and emergence. Moreover, the seed size and seedling length were inversely proportional where larger size seeds (SC701) yielded shorter seedlings compared to smaller size seeds of MMP. These results were consistent with findings of McKersie (1981). However, Akinnuoye and Modi (2015) reported smaller seeds to have faster germination than larger seeds.

4.2.2 Electrolyte conductivity

Hourly electrolyte conductivity (µS/ g) showed highly significant differences ($P < 0.001$) among maize cultivars (Figure 4.2). These observations were similar to several reports in the literature (Odiemah, 1989; Mabhaudhi and Modi, 2010; Mazvimbakupa *et al*., 2015). Zama star and MMP were statistically similar while they were significantly different from SC701. The SC701 hybrid was shown to have the highest electrolyte conductivity (EC), followed by ZS and MMP, respectively. This would imply that the cultivar with high seed vigour was MMP, followed by ZS and SC701, respectively. The results of EC contrasted results of the standard germinations test, although they were similar to observations from the TZ test. Previous studies have reported a significant relationship between EC and germination where high germination was associated by low EC (Thornton *et al*., 1990). This indicates a negative correlation that exists between EC and germination (McKersie, 1981). High and low vigour seeds can be characterised on the basis of low and high EC, respectively (Milosevic *et al*., 2010). High EC indicates high electrolyte leakage which is associated with low vigour seeds. Deteriorating and low vigour seeds commonly have poor or degenerated membrane structure which enhances leaky cells (AOSA, 2002).

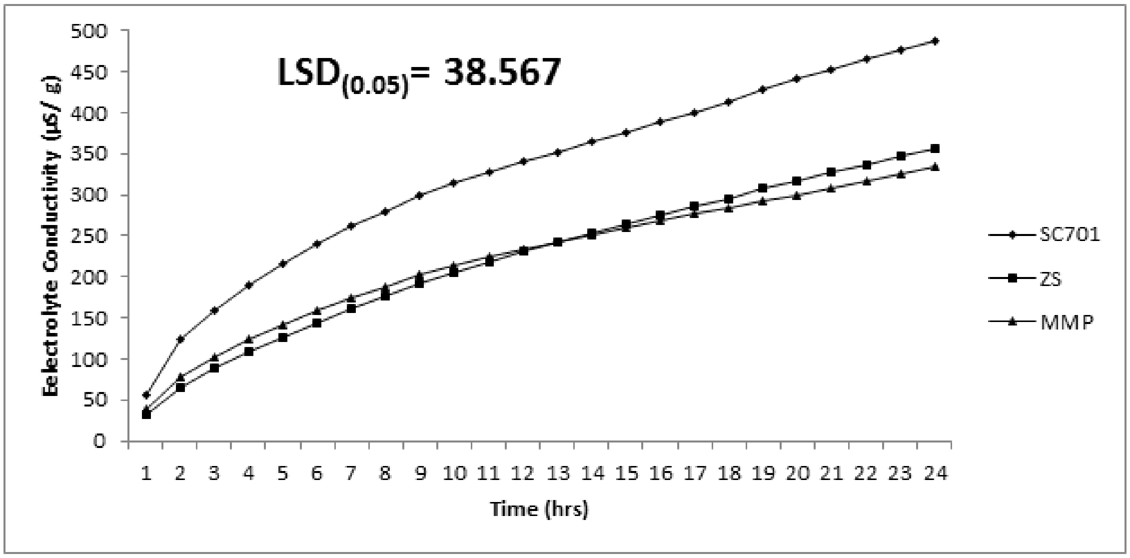

Figure 4.2: Electrolyte conductivity (EC) of maize cultivars Mac Medium Pearl (MMP), SC 701 and Zama Star (ZS).

In addition to cultivar differences, EC is affected by other factors such as seed storage conditions, seed pathogens, initial water content of seeds, and seed physiological quality (Vieira *et al*., 2002; Panobianco *et al*., 2007). Initial seed moisture is related to electrolyte leakage, where low moisture content yields high rates of EC than high moisture seeds (Marks and Stroshine, 1998). This trend was also evident in this current study. The rate of electrolyte leakage also increased with an increase in seed mass (1000 grain mass) (Table 4.1).

4.3 Conclusion

The findings of this study show that the superior maize cultivar in terms of seed viability was SC701 followed by ZS and MMP, respectively. Cultivar SC 701 had lowest moisture content which was associated with high germination rate and consequently final germination percentage. The superior seed quality (germination vigour and viability) of SC701 was also confirmed by several vigour indices such as 1000 grain mass, GVI, root: shoot ratio and MGT. There was no agreement between seed viability and vigour tests. Electrolyte conductivity test showed that SC701 was inferior in terms of seed vigour. The variations in observations from different seed viability and vigour tests emphasis the need to not rely on only set as this may be inconclusive. In addition to such seed testing, there is still need to determine the field planting value of a seed lot as this would provide more value to farmers.

CHAPTER 5

MAIZE PHYSIOLOGY, GROWTH AND YIELD RESPONSES TO SIMULATED HAIL DAMAGE

5.1 Introduction

Maize is the most important grain crop in South Africa (du Plessis, 2003). As a major crop, maize has received significant breeding attention. As such, there are several varieties of maize that farmers can select for planting. This introduces the aspect of cultivar selection since different cultivars have different characteristics and consequently varying adaptability and yield potential. It is therefore important for farmers to select cultivars that are best suited to local conditions in order to ensure successful production (du Plessis, 2003). Like many crops, maize also needs to be adapted to changes in the environment to which it is cultivated. Plants may be injured by various extreme weather events such as high winds, hail and heavy rain. These conditions enhance plant defoliation with a negative impact on marketable yields (Bartolo et al., 1994). Therefore, in addition to other good agricultural practices, it is important to select maize cultivars that are adapted to such climatic conditions as hail damage.

It is common practice in research to use defoliation as simulated hail damage (Trappeniers et al., 1992). Not only does defoliation decrease marketable yield, it generally induces sterility, rapid plant desiccation and delayed crop maturity (Hepting, 1990; Bartolo et al., 1994). This is attributed to the significant reduction of functional leaf area responsible for photosynthesis and predisposes plants to pathogenic infections (Bartolo et al., 1994). The level of yield reduction is determined by genotype, the level of defoliation, environmental conditions and plant growth stage at which defoliation occurs (Hicks et al., 1977; Gay and Bloc, 1984; Vasilas and Seif, 1985b; Thomison and Nafziger, 2003). According to a study by Barimavandi et al. (2010), defoliation had a significant effect on grain yield and yield components. The authors alluded that complete defoliation enhanced severe reduction of grains on cobs. Considerable yield losses occur when plants are defoliated at a later/final growth stage (Malone and Calviness, 1985). However, Trappeniers et al. (1992) reported that leaf shredding significantly affected grain yield regardless of the stage of damage.

Plant growth stage at which damage occurs also plays an important role in terms of crop recovery and growth compensation. There can be growth compensation if damage occurs before reproductive stage or during the transition from vegetative and reproductive growth (Conley et al., 2008). Young leaves often survive damage thus conferring high probability for recovery since they have high photosynthetic rates. However, maize plants do not wholly depend on direct leaf photosynthesis for photosynthates, the crop can also photosynthesise from other green plant parts such as stem and green husks (Hashemi and Maraashi, 1993). However, the photosynthetic ability of stems and ear husk is not as efficient as the leaves that play the chief role of photosynthesis in plants.

Under normal conditions, assuming no extreme weather events, maize performance is also subject to agronomic factors such as plant population density (Vega et al., 2001; Sangakkara et al., 2004). According to Sangakkara et al. (2004), competition for resources between plants increases with an increase in the number of plants. This competition affects solar radiation interception, nitrogen, photosynthates and water use (Zamir et al., 2011); this can have an effect on subsequent yields achieved at different plant densities. At high plant densities, mutual shading induces low photosynthetic rates and high respiration rates (Zamir et al., 2011). However, high plant population densities have been associated with enhancements of physiological growth parameters such as leaf area index and total dry mass (Saberali, 2007; Valadabadi and Farahani 2010). This was attributed to the fact that photosynthesis increases with an increase in leaf area development (Valadabadi and Farahani, 2010). According to a study by Abuzar et al. (2011), there were significant differences between different plant population densities with respect to leaf area index and ear prolificacy in maize. High ear prolificacy was associated with low relative to high plant densities whereas LAI and plant population had a linear relationship (Abuzar et al., 2011). Elsewhere, Zamir et al. (2011) reported that low plant density resulted in high grain mass due to improved water and nutrient availability.

Several studies have focused on plant stresses such as defoliation, rain, wind and herbivory, among others. Limited research has been dedicated to hail damage, particularly in maize. Furthermore, there has not been an effort to associate hail damage with plant densities. Therefore, the aim of this study was to determine the interactive effect of hail damage and plant density on physiology, growth and yield of maize.

5.2 Results and Discussion

5.2.1 Maize physiology and growth

5.2.1.1 Stomatal Conductivity (SC)

There were significant ($P<0.05$) differences between plant densities and sites as well as the interaction of these factors with respect to stomatal conductance (Figure 5.1). Moderate plant population density had high stomatal conductance, with Baynesfield having higher SC than Swayimane for all plant densities (Figure 5.1). Since stomatal conductance can quantify photosynthesis and transpiration in plants with the aid of portable porometer (Tartachnyk and Blanke, 2008), it is therefore obvious that maize plants at moderate density and in Baynesfield environment have high rate of photosynthesis and transpiration as indicated by high stomatal conductance.

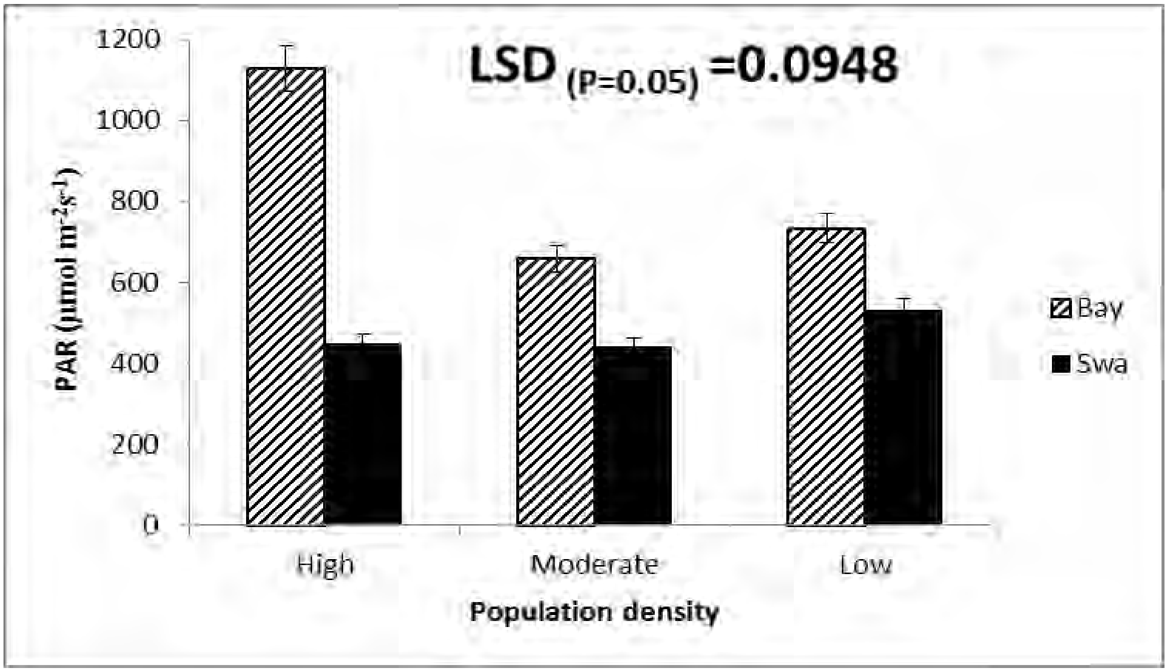

Figure 5.1: Stomatal conductance of maize in response to plant density at Baynesfield (Bay) and Swayimane (Swa) environment.

There was no significant interaction between cultivars and hail damage. Contrary to expectation, SC701 and MMP recorded the highest stomatal conductance when hail damage occurred at VT relative to V7 and the control (Figure 5.2). This may be an indication that these cultivars are more tolerant to hail damage particularly at VT stage. However, with cultivar ZS the opposite was true. Cultivar ZS showed high stomatal conductance when there is no hail damage relative to when there was hail damage. The observations for the ZS cultivar were consistent with Tartachnyk and Blanke (2008) who argued following hail damage plants tended to close their stomata. This closing of stomata subsequently decreases photosynthesis and transpiration. However, due to subsequent re-opening of stomatal, hail-damaged plants usually recovered (Tartachnyk and Blanke, 2008).

Stomatal conductance varied significantly (P<0.05) over time in response to plant density (Figure 5.3 A and B). Moderate plant density recorded high stomatal conductivity at both sites. However, with respect to this same density, Baynesfield (Figure 5.3 B) showed a unique trend which was decreasing over the period of three weeks whereas Swayimane (Figure 5.3 A) started by increasing from11 WAP to 13 WAP and then decreased from 13 WAP and 15 WAP.

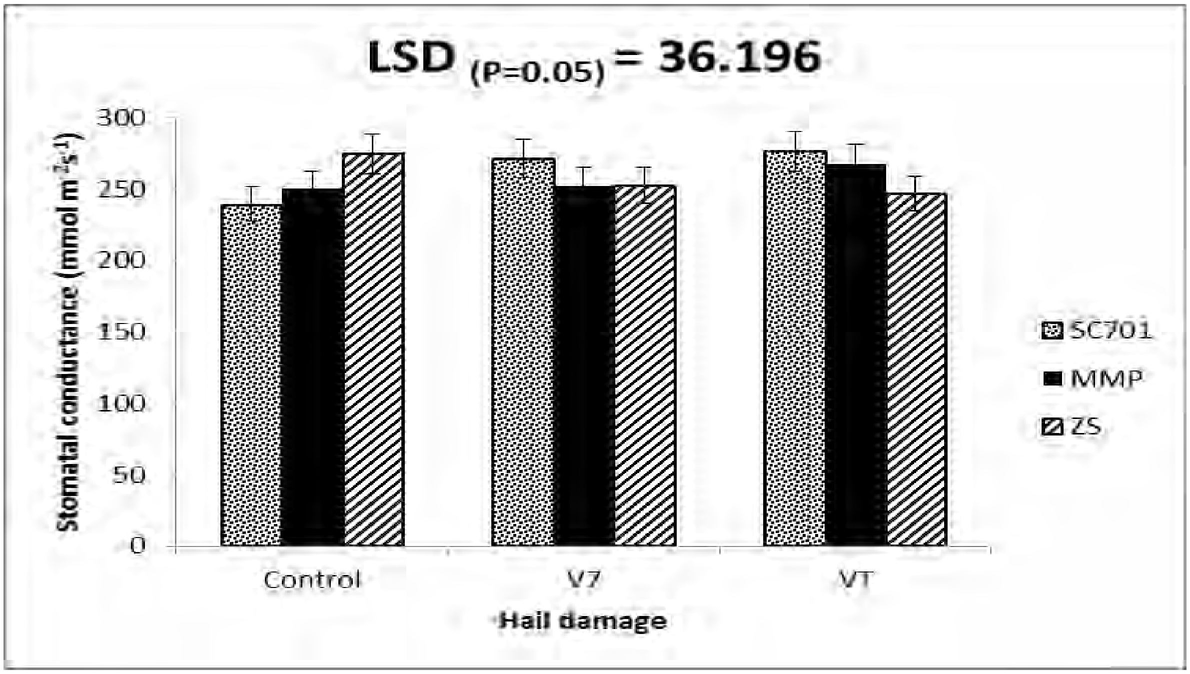

Figure 5.2: Stomatal conductance of maize cultivars (SC701, MMP and ZS) in response to simulated hail damage.

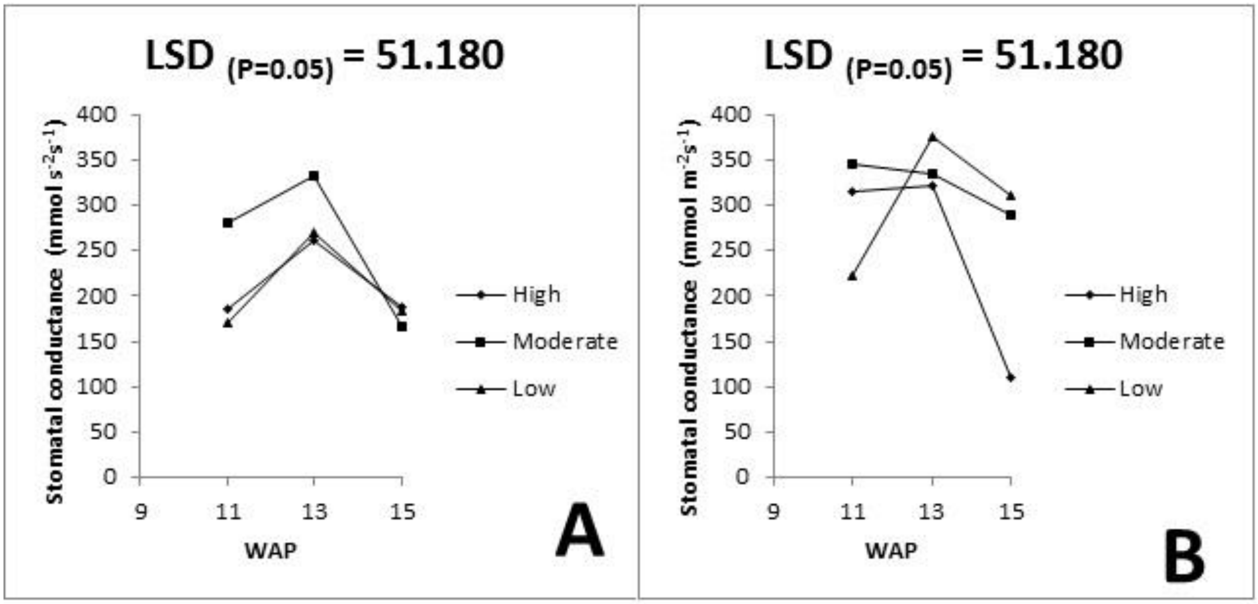

Figure 5.3: Stomatal conductance change over time after at different plant densities measured at Swayimane (A) and Baynesfield (B).

5.2.1.2 Chlorophyll content index

There were significant differences (P<0.05) between maize cultivars with respect to chlorophyll content index (CCI). Cultivar MMP had the highest CCI throughout the observed period compared to SC701 and ZS (Figure 5.4). In addition to genotypic differences, differences in the chlorophyll content index may be attributed to differences in the time it takes for the cultivars to mature. MMP matured earlier relative to the other varieties; this may have resulted in this cultivar having highest chlorophyll content throughout the recorded period (Figure 5.4). Conversely, cultivar SC701 took longest to mature which was confirmed by low chlorophyll content as the recording period probably ended earlier than its peak vegetative period (Figure 5.4).

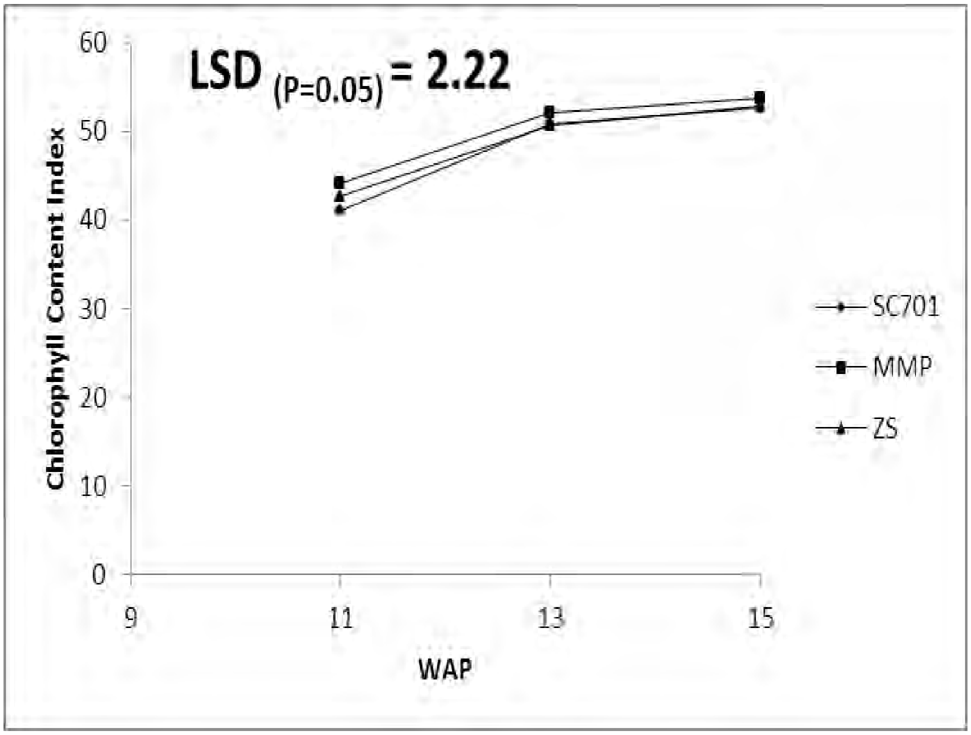

Figure 5.4: Change of Chlorophyll Content Index of three maize cultivars (SC701, MMP and ZS) over time.

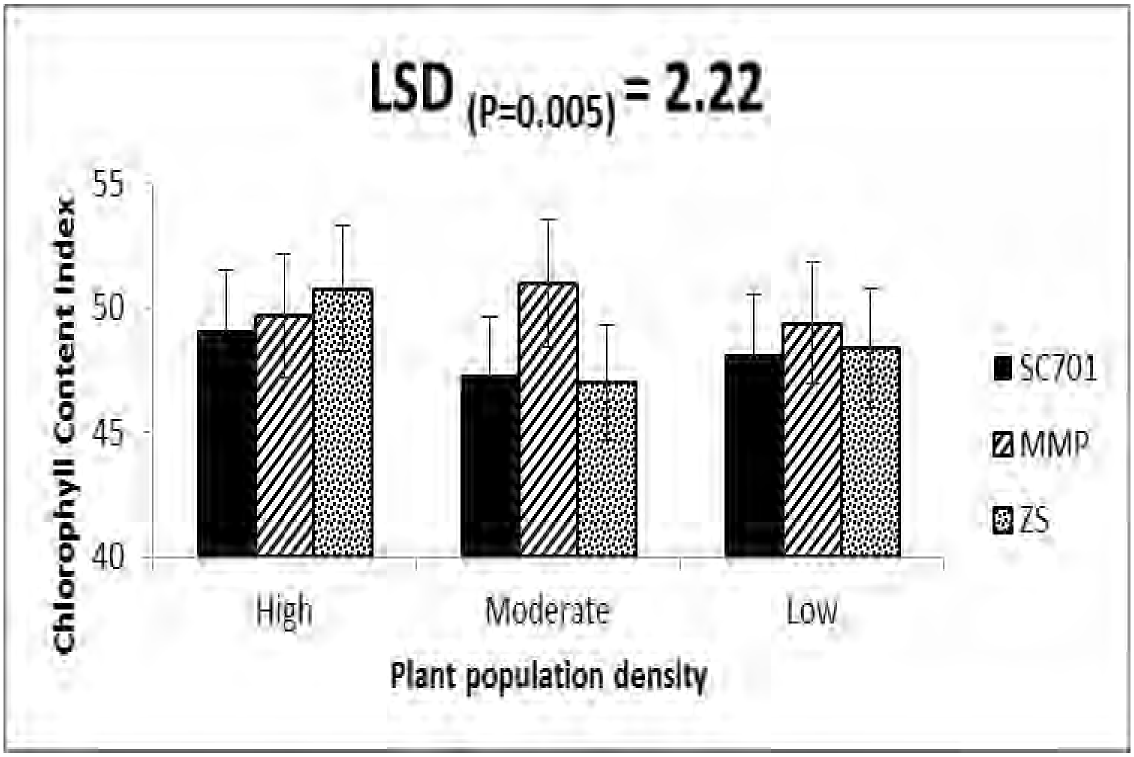

Figure 5.5: Chlorophyll Content Index response of maize cultivars (SC701, MMP and ZS) under different plant densities.

There were highly significant differences ($P<0.001$) between sites with respect to chlorophyll content index (CCI). Maize grown at Baynesfield showed higher CCI than that grown at Swayimane. There was also significant interaction ($P<0.05$) between cultivar and density. Even though cultivar MMP expressed high CCI, under moderate plant density ZS exhibited highest CCI (Figure 5.6). Maize cultivars responded differently at different densities in terms of chlorophyll content.

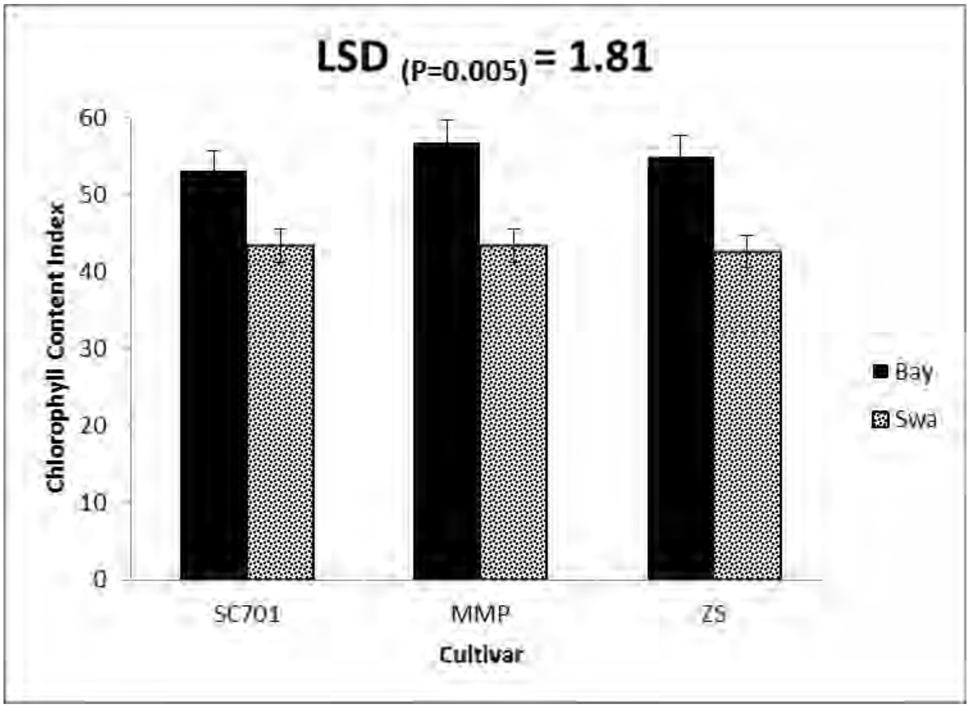

Figure 5.6: Chlorophyll Content Index response of maize cultivars (SC701, MMP and ZS) at Baynesfield and Swayimane.

There were also significant interactions (P<0.05) between cultivar and site. Evidently, Baynesfield had higher content of chlorophyll with cultivar MMP being superior at both sites (Figure 5.6).

5.2.1.3 Leaf number

Cultivar, density, hail, site had a significant influence (P<0.001) on leaf number. However, there was no significant difference between SC701 and MMP and the highest leaf number expressed by SC701.

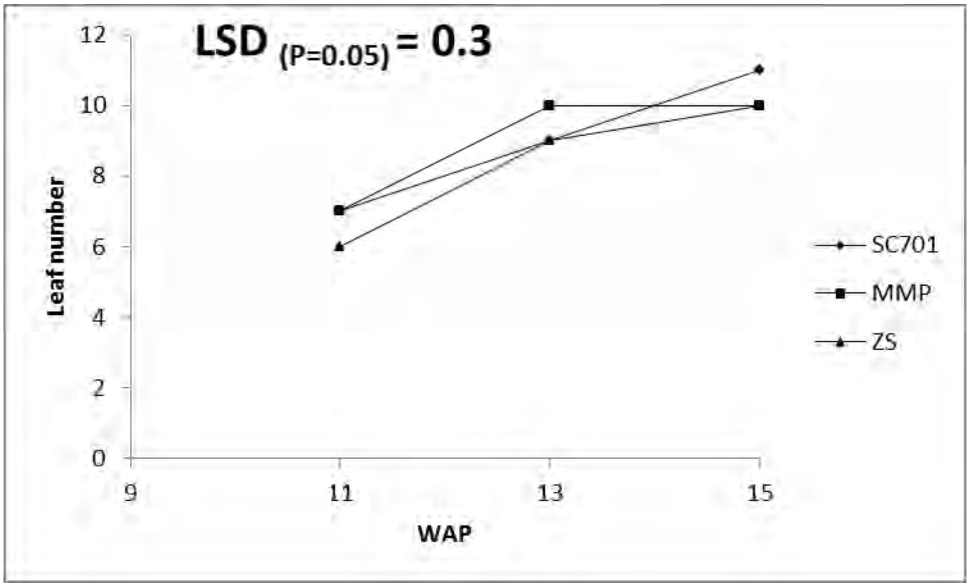

Figure 5.7: Change of leaf number of three different maize cultivars (SC701, MMP and ZS) over time.

There were also highly significant two way interactions ($P<0.001$) between site with cultivar as well as between density and hail damage. Maize grown at Baynesfield had high leaf number than maize grown at Swayimane (Figure 5.8). Shafiullah et al. (2001) argued that after leaf damage or defoliation, there was often a great chance of compensation from a high amount of young leaves remaining which were still able to translocate assimilates to the flowers and seeds. In particular, the upper leaves (source) usually contributed more towards sinks (seeds) than the lower older leaves. In addition, the upper leaves intercept radiation more than lower leaves which means that they are more photosynthetically activity (Shafiullah et al., 2001).

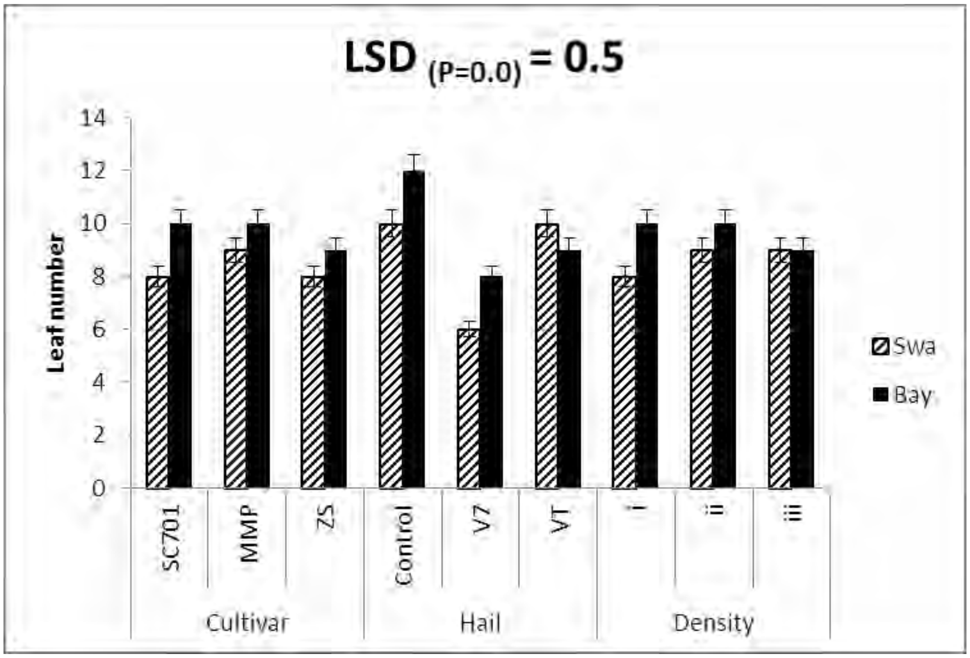

Figure 5.8: Maize leaf number in response to cultivar, hail damage and plant population density at two different sites (Baynesfield and Swayimane).

5.2.1.4 Plant height

There were highly significant effects (P<0.001) of cultivar, density and site on maize height. Baynesfield had the tallest plants than Swayimane over time (Figure 5.9). The significant difference between cultivars for plant height were in line with Polat et al. (2011). In the current study, plant height among the cultivars decreased from SC701, MMP and ZS, respectively. On the other hand, plant height at different plant population densities decreased from high, moderate and low, respectively. This was in line with Dahmardeh (2011) that not only plant height evidently increased at high plant density but consequently light interception (absorption of PAR). This enhances vegetative growth to become more extended resulting in great leaf production that yields high amount of assimilates produced to increase plant height. In addition, there is high light interception which in turn results in high grain yield (Tollenaar et al., 1997; Amanullah et al., 2009).

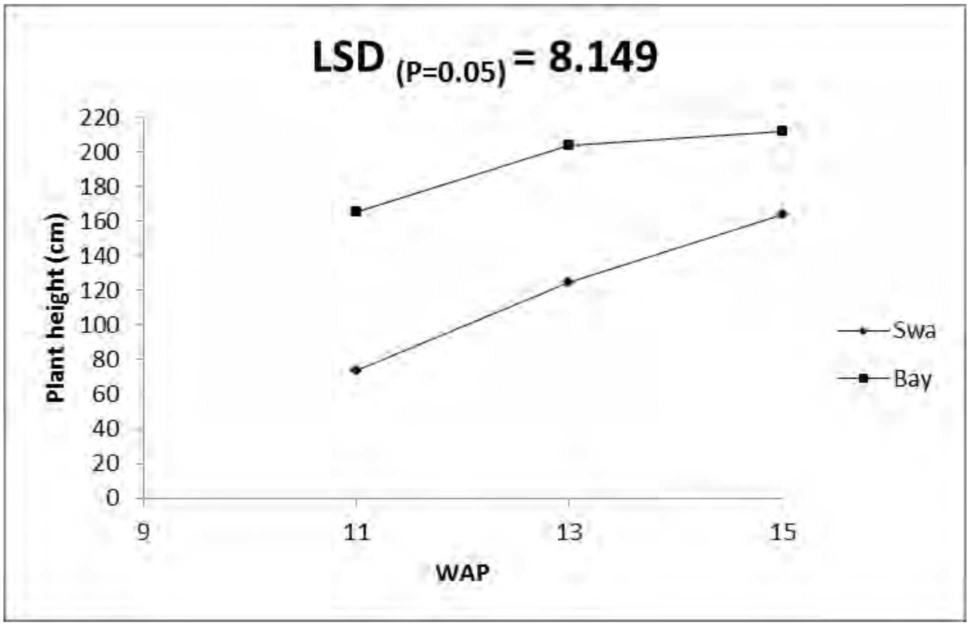

Figure 5.9: Maize plant height, based on means of maize varieties across plant densities, measured at Swayimane and Baynesfield.

Even though hail damage had no effect exclusive of other factors, there were significant interactions ($P<0.05$) involving hail damage. These results were consistent with reports by Legwaila et al. (2013) where hail damage, alone, had no effect on plant height. Hail damage interacted with plant density and cultivar to influence plant height (Figure 5.10). Consistent with findings of this study, Battaglia (2014) also reported that there were different responses of maize hybrids to defoliation at different plant population densities. According to a study by Polat et al. (2011), plant height decreased with defoliation compared to no defoliation. In this study, this was only evident in cultivar MMP at low plant density and ZS at plant moderate density. This confirms that maize cultivars respond differently to defoliation at different plant population densities.

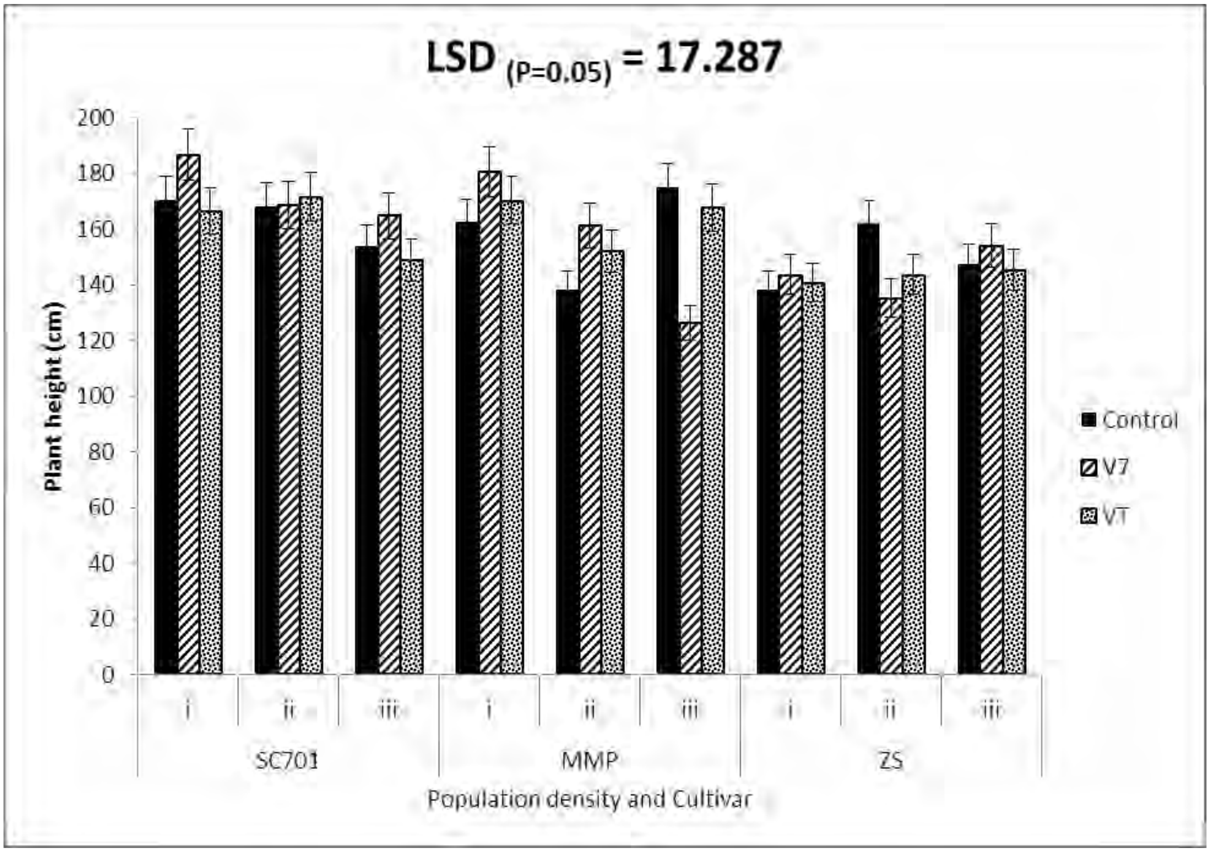

Figure 5.10: Plant height response of maize cultivars (SC701, MMP and ZS) to hail damage at different plant densities.

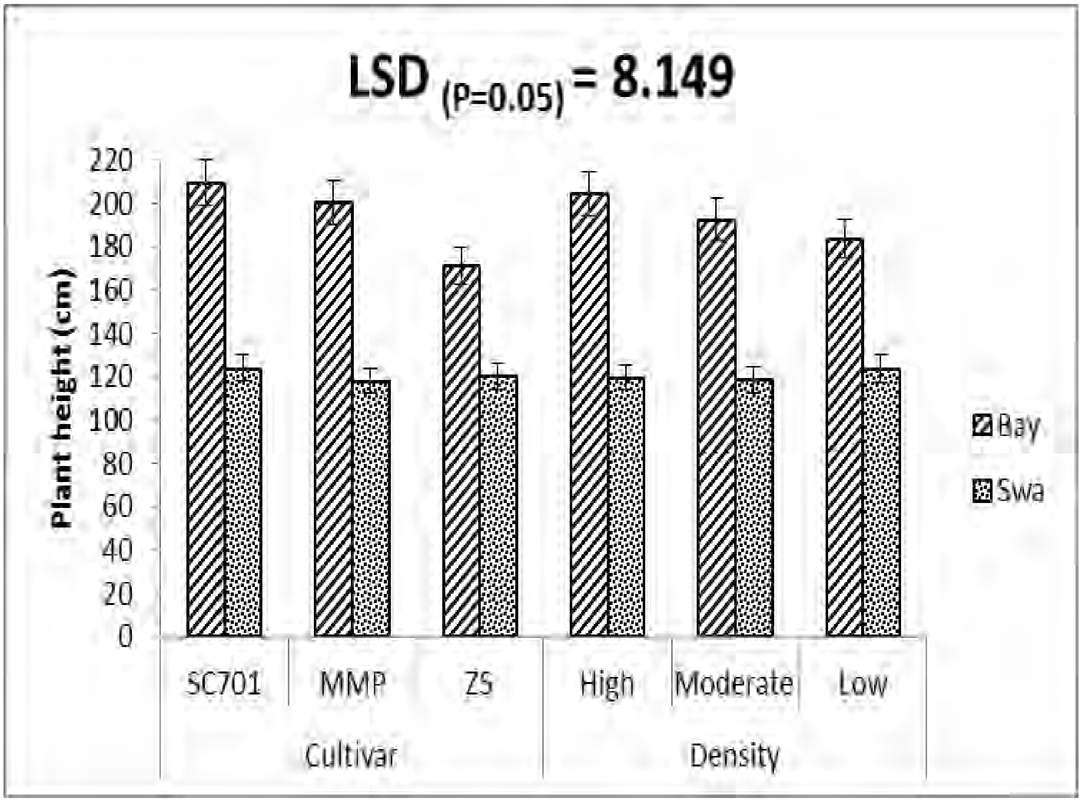

Figure 5.11: Response of maize plant height to different cultivars (SC701, MMP and ZS) and plant densities at two different sites (Baynesfield and Swayimane).

Furthermore, there were significant interactions ($P<0.05$) between site with cultivar and site with plant density. Cultivar SC701 had the tallest plants in both sites. Even though high plant density yielded tallest plants in Baynesfield, at Swayimane the tallest plants were found under low density (Figure 5.11).

5.2.1.5 Leaf Area Index

Leaf area index varied significantly ($P<0.05$) with respect to the interaction of plant density and site (Fig 5.12). These results were in line with Abuzar et al. (2011). High plant density had plants with high LAI and moderate had lowest, with Baynesfield performing better than Swayimane. High plant population densities have been associated with enhancements of physiological growth parameters such as leaf area index (Saberali, 2007; Valadabadi and Farahani 2010). In turn, this trend also increases photosynthesis of plants (Valadabadi and Farahani, 2010). On the other hand, small leaf area for radiation interception reduces photosynthesis which may consequently reduce seed yield (Polat et al., 2011). Despite the reported benefits of leaf area development at high plant density, Hassan (2000) reported that leaf area decreased with increase in maize density.

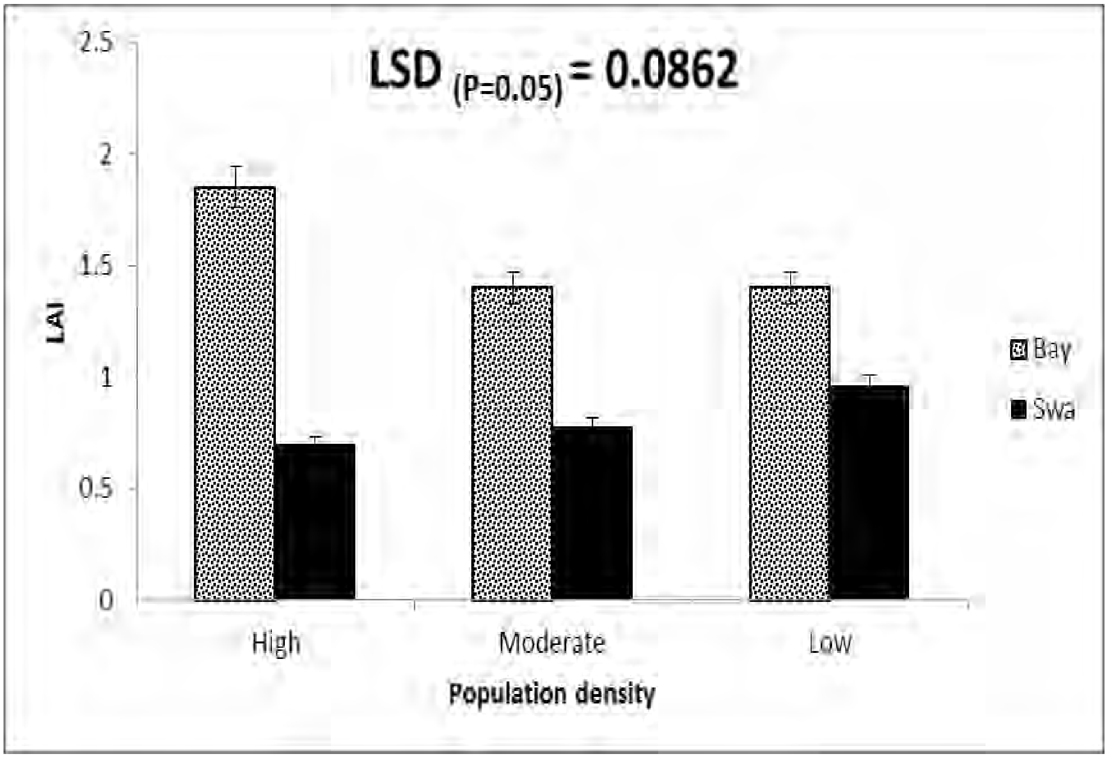

Figure 5.12: Maize LAI in response to plant density at different sites (Baynesfield and Swayimane).

The interaction between maize cultivars and hail damage was significant (P<0.05) with respect to LAI (Figure 5.13). Maize cultivar SC701 had high LAI compared to MMP and ZS, respectively, with the Control being superior to VT and V7. There were also significant interactions (P<0.05) between plant density and site as well as between cultivar, site and hail damage treatments for plant LAI (Figure 5.13). Previous authors have reported the significance of plant stage at which defoliation is inflicted (Gazzoni and Moscardi, 1998; Legwaila et al., 2013). Defoliation at a later stage of plant development (VT) significantly reduced LAI compared to when defoliation occurred earlier (V7) and no defoliation, respectively. Contrary to the negative impact of defoliation at a later stage of crop development (Legwaila et al., 2013), it was reported that plants have an ability to recover from defoliation when damaged at vegetative stage (Gazzoni and Moscardi, 1998).

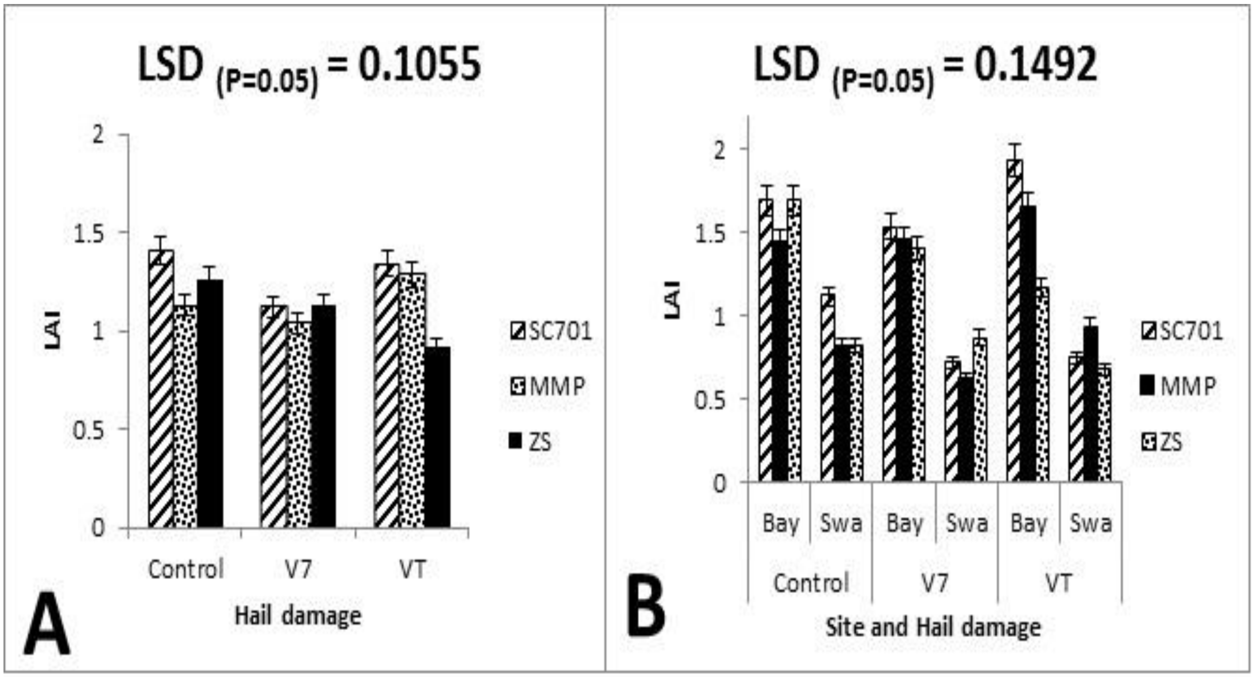

Figure 5.13: Leaf area index (LAI of three maize cultivars (SC701, MMP and ZS) in response to (A) simulated hail damage, and site x simulated hail damage interaction (B).

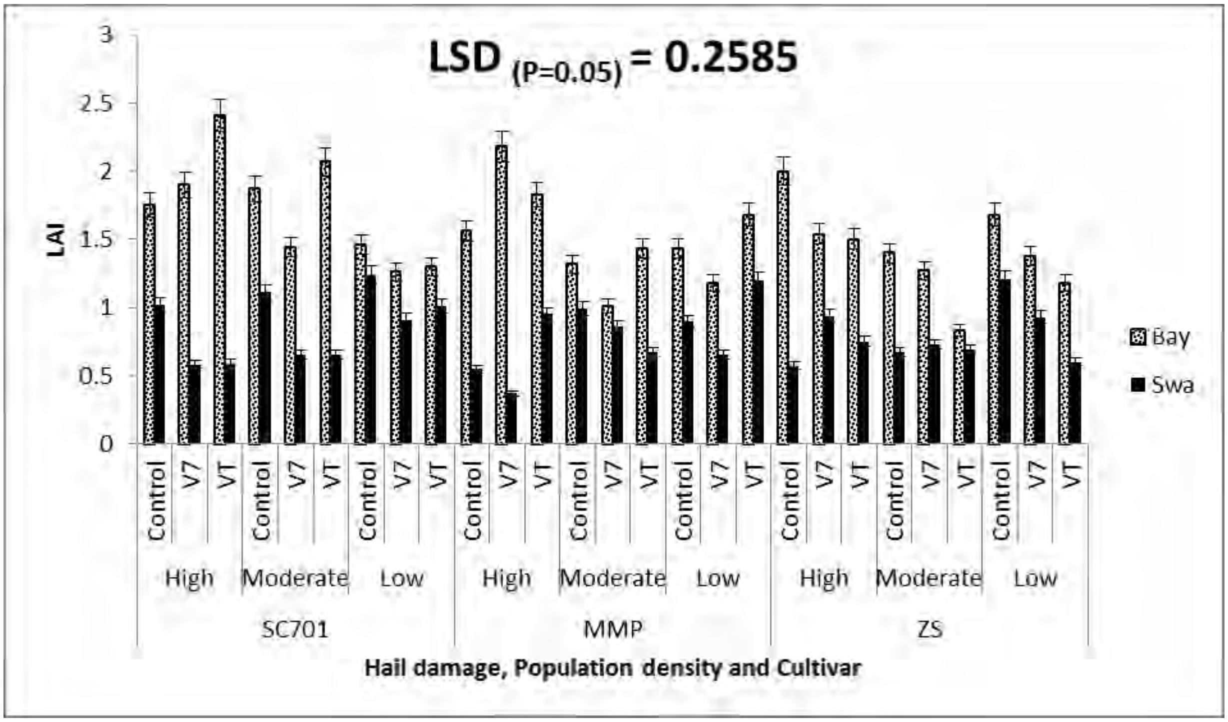

Figure 5.14: LAI of maize cultivar (SC701, MMP and ZS) in response to simulated hail damage and plant densities at different sites [Bay (Baynesfield) and Swa (Swayimane).

There was a significant four way interaction (P<0.05) of cultivar, density, hail and site on maize LAI. The LAI of different cultivars under different plant densities at different sites responded differently to simulated hail damage. Even though Baynesfield had higher LAI compared to Swayimane, the control (no hail damage) for all three cultivars, especially from cultivar SC701 had the highest LAI for most plant density treatments (Figure 5.14). The highest LAI was at high plant density when hail damage was applied at VT of cultivar SC701. Cultivar MMP, at high density with hail applied at V7, had the lowest LAI. This was an indication that at similar density the interaction of site, cultivar and hail damage can yield different results opposite to the individual factor effect.

5.2.1.6 Photosynthetically Active Radiation

There were significant differences (P<0.05) between plant densities, sites, and interaction between plant density and site, with respect to photosynthetically active radiation PAR. High plant density had highest PAR followed by moderate and low plant densities, respectively. These results were in line with Edwards et al. (2005) who reported that under high plant densities there was often great amount of PAR which often translated to high crop yield. However, at Swayimane, PAR increased with an increase in plant density. In terms of the environment, even though there was difference in response of PAR to plant density at different sites, Baynesfield performed better than Swayimane.

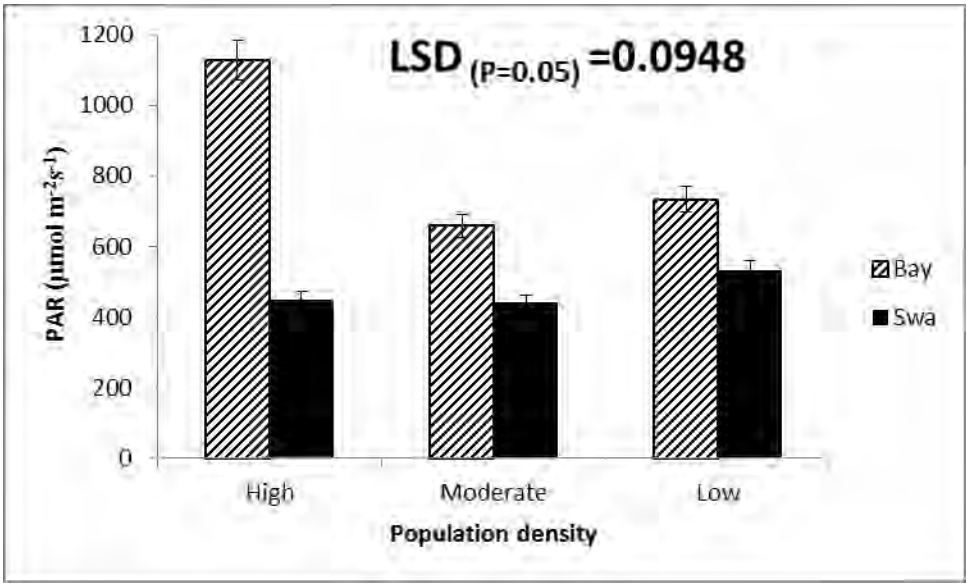

Figure 5.15 Photosynthetically Active Radiation (PAR) of maize plants in response to plant densities (High, Moderate and Low) at two sites (Baynesfield and Swayimane).

5.2.2 Maize yield and yield components

5.2.2.1 Cob length

There were significant effects ($P<0.05$) of cultivar, site and interaction between cultivar and site on maize cob length. Hail damage had no significant effect on cob length which was in line with Heidari (2013). The cultivars responded differently at different sites. At Swayimane, cultivar ZS had longest cobs compared to SC701 and MMP, respectively. However, at Baynesfield the superiour cultivar with respect to cob length is SC701 and inferior is MMP (Figure 5.16). In terms of the environment, Baynesfield produced maize cobs that are longer than those from Swayimane.

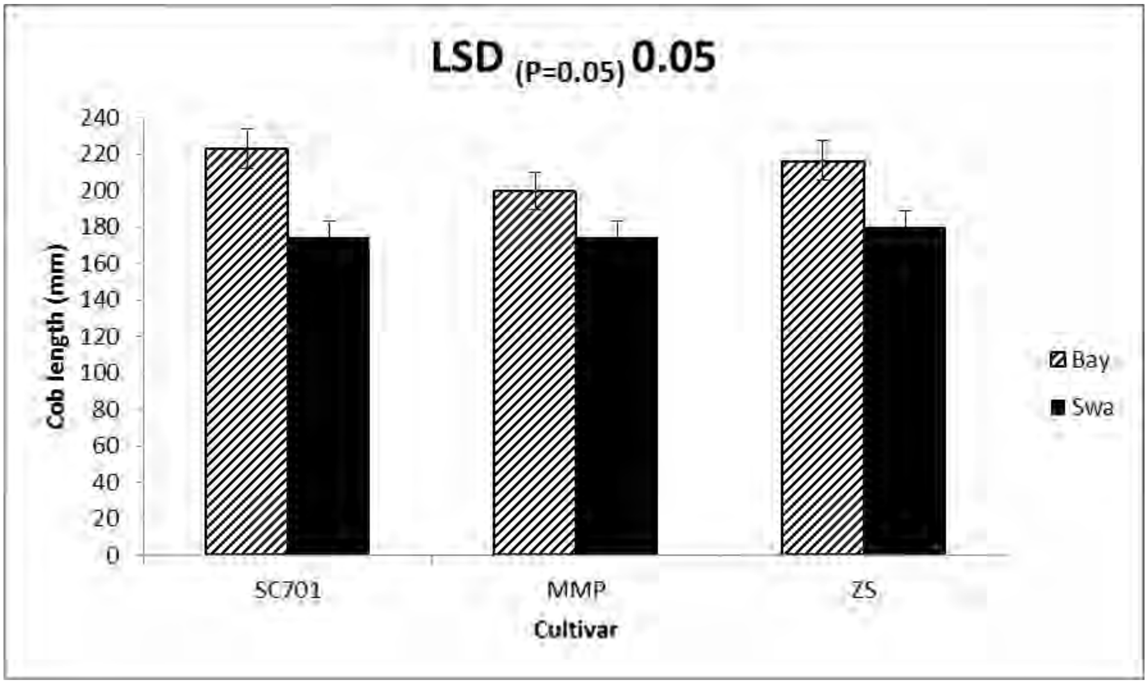

Figure 5.16: Cob length of different maize cultivars (SC701, MMP and ZS) at different sites [Baynesfield (Bay) and Swayimane (Swa)].

Figure 5.17: A random sample of cobs of three maize cultivars harvested from both experimental sites.

Even though the cultivars were significantly different, MMP and ZS were not significantly different and SC701 had the longest cobs (Figure 5.16).

5.2.2.2 Cob mass

There were highly significant effects (P<0.001) of cultivar, site and cultivar by site interaction on maize cob mass. SC701 had the highest cob mass which also reflected at Baynesfield, however, ZS had the highest cob mass in Swayimane. The comparison of both sites showed that Baynesfield outperformed Swayimane in terms of cob mass (Figure 5. 18).

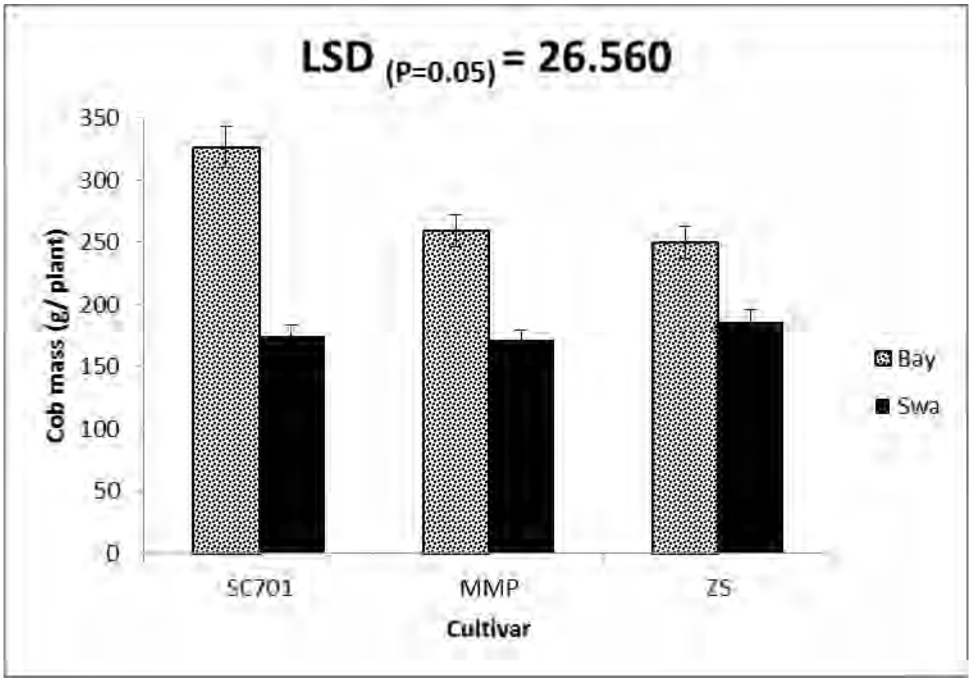

Figure 5.18: Cob mass of different maize cultivars (SC701, MMP and ZS) in two sites [(Bay = (Baynesfield)and Swa (Swayimane)].

Even though not significantly different (P>0.05), the superior plant cob mass in response to hail damage followed the decreasing trend from Control, V7 and VT; respectively, which was evident for both sites (Figure 5.18 and Figure 5.19). These results concur with Legwaila et al. (2013) who found grain mass to be reduced significantly when plants are defoliated at later stage of plant growth compared to an earlier stage and no defoliation. Borras et al. (2004) further alluded that grain mass in maize is very sensitive to reduction in production of assimilate during seed filling. However, Trappeniers et al. (1992) reported that leaf shredding significantly affected grain yield regardless of the stage of growth during damage.

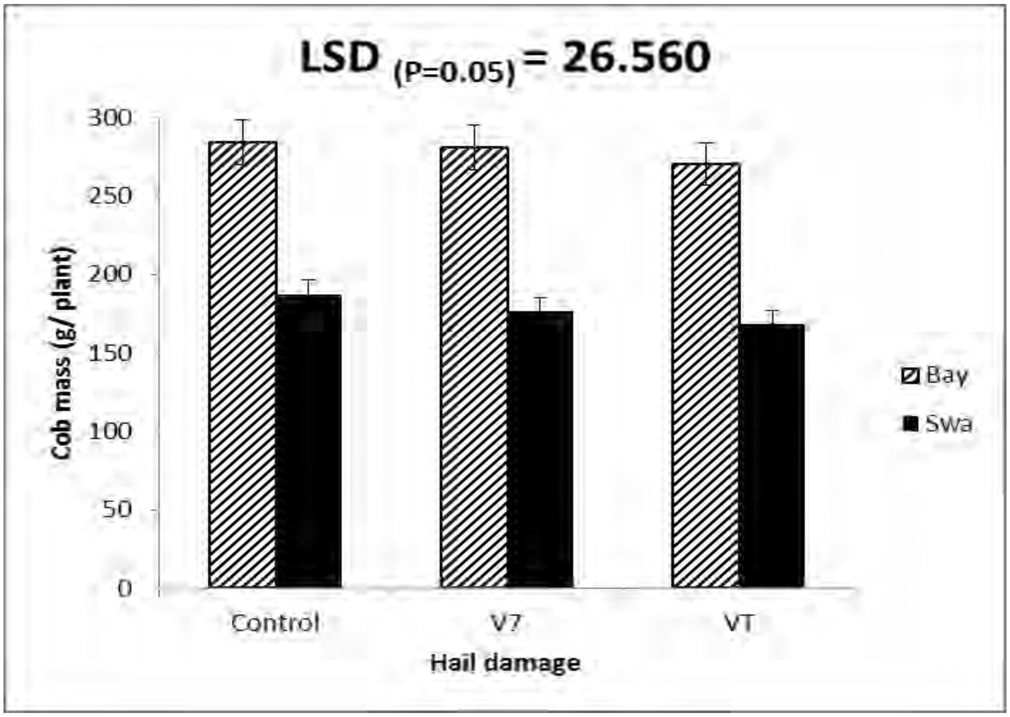

Figure 5.19: Cob mass of maize plants from Baynesfield and Swayimane.

Figure 5.20: Maize cobs harvested from three different hail damage treatments.

5.2.2.3 Maize ear prolificacy

There were highly significant differences ($P<0.001$) between sites with respect to ear prolificacy. Baynesfield had higher ear prolificacy than Swayimane (Figure 5.21). While the current study showed no significant effect of plant densities on ear prolificacy, this was contrary to previous reports by Abuzar et al. (2011) that low plant population density produced high ear prolificacy compared to high plant density.

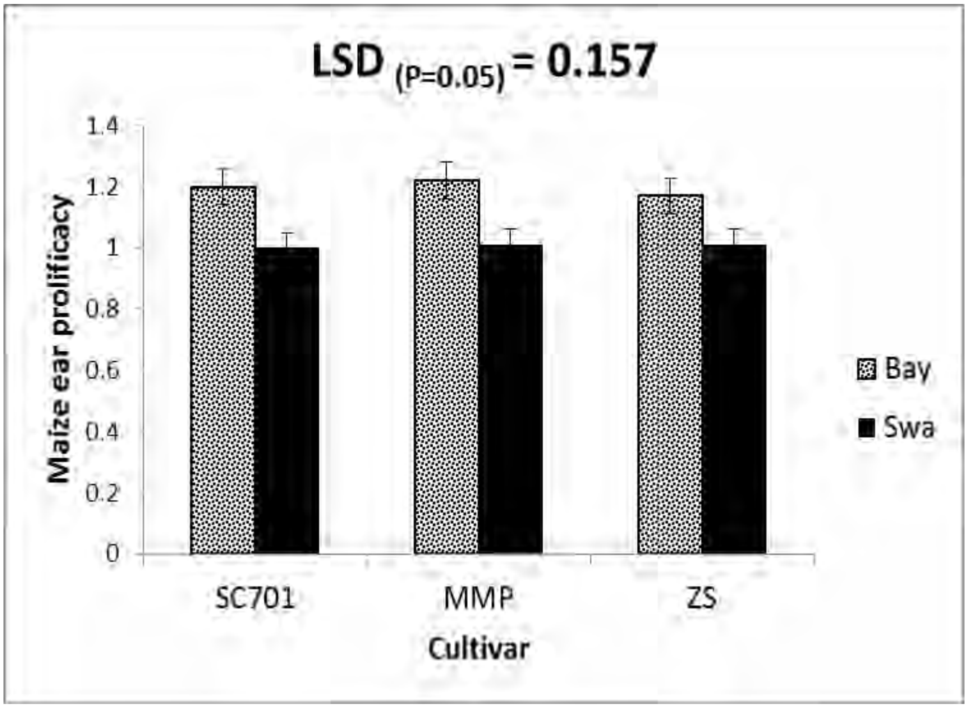

Figure 5.21: Maize ear prolificacy of different cultivars (SC701, MMP and ZS) at Baynesfield (Bay) and Swayimane (Swa).

5.2.2.4 Seed mass

There were highly significant differences ($P<0.001$) between cultivar, site, seed position on the cob and the interaction between cultivar and site. With proximal seed being heavier than distal seeds, the highest seed mass was recorded for SC701 and lowest for MMP cultivars. Baynesfield produced heavier seeds than Swayimane (Figure 5.22). It was also reported in other study that cultivars had a significant effect ($P<0.05$) on seed yield (Vasilas and Seif, 1986; Siahkouhian, 2012).

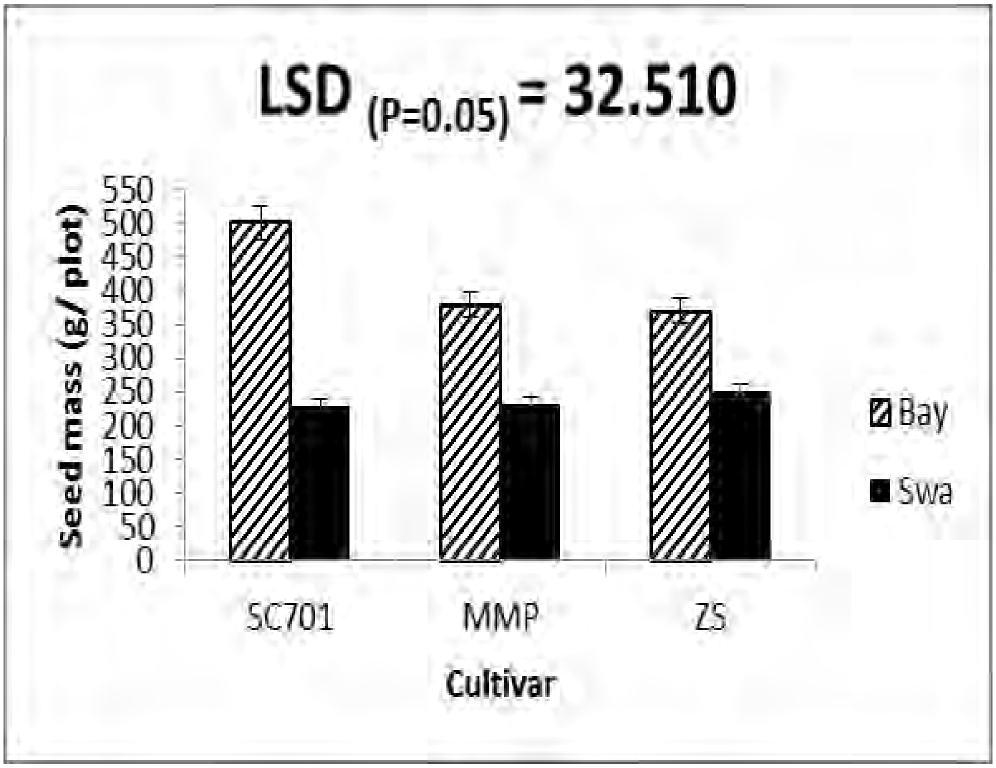

Figure 5.22: Seed mass of maize cultivars (SC701, MMP and ZS) from Baynesfield (Bay)and Swayimane (Swa).

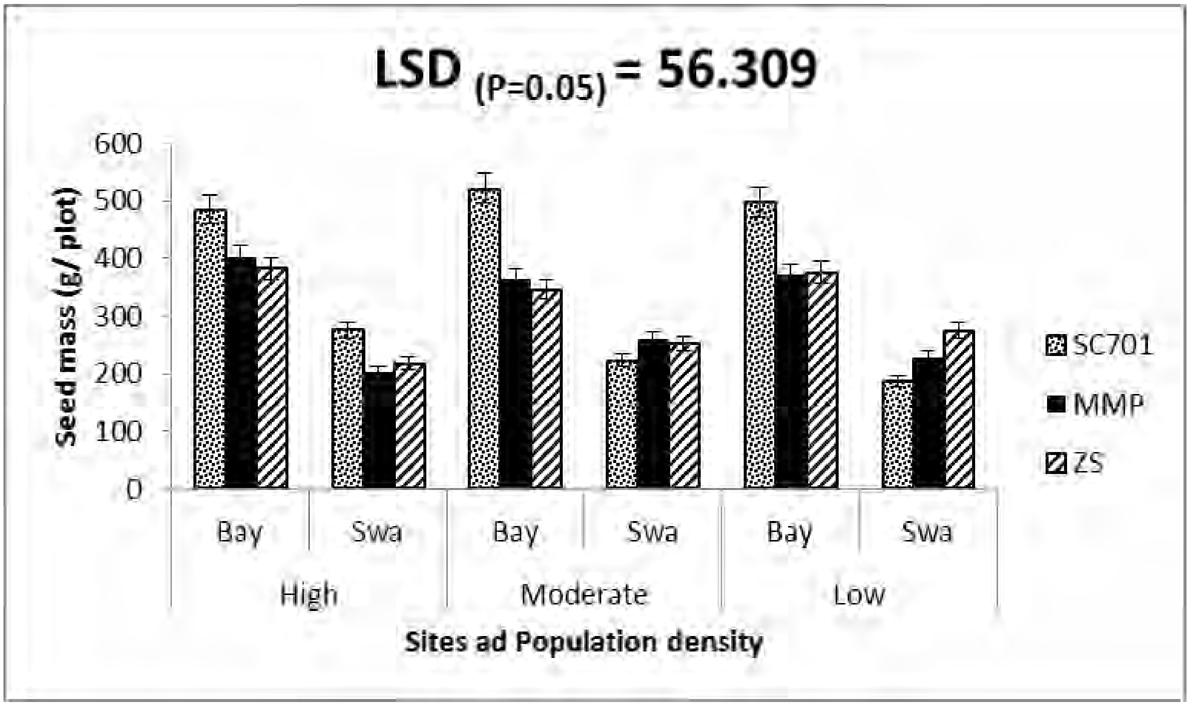

Figure 5.23: Seed mass of different maize cultivars (SC701, MMP and ZS) at different plant densities from Baynesfield (Bay) and Swayimane (Swa).

Even though simulated hail damage had no significant (P>0.05) effect on seed mass, the control (no hail damage) had high seed mass compared to hail damage (V7 and VT, respectively). These results are in line with (Heidari, 2013). In hail damaged treatments, the lower seed mass was attributed to the loss of photosynthetic leaf area (Kopture et al. 1996) responsible for translocation of the photo-assimilates to the developing seed

On the contrary, Barimavandi et al. (2010) and Polat et al. (2011) reported that there was a significant effect of defoliation on grain yield and yield components. Similar to this study, Malone and Calviness (1985) Erbas and Baydar (2007) also found plants to have considerable yield losses when defoliated at a later/final growth stage than earlier stage. Plant tolerance to hail damage when they are still small is enhanced by the fact that the growing point at that stage is below the ground level and grain yield reduction is relatively insignificant (Lee, 2007). Grain yield losses due to defoliations around tasselling/silking are generally expressed by fewer number of seeds (Severini et al., 2011), contrary to before or at grain filling which is expressed by the decline in kernel mass (Abendroth et al., 2011).

5.3 Conclusion

The results of this study show that maize cultivars, environment, plant population density and the interaction of these factors were significantly different in affecting maize response and recovery from simulated hail damage. Cultivar SC701, no hail damage (control) or hail damage at V7 with high plant population density and Baynesfield environment is the superior in affecting positive maize growth and yield. However, not all crop growth and yield responses adhered to this trend. Therefore, crop management manipulation such as cultivar selection, varying plant population and planting maize in different environments was found to be important in mitigating hail damage effects on maize physiology, growth and yield. More research can still be done on the effect of hail damage not only in maize but other agronomic crops in order to mitigate the negative effect of hail damage with considerations other effects of hail in addition to damage.

CHAPTER 6

QUALITY OF MAIZE SEEDS FROM PROXIMAL AND DISTAL EAR POSITION IN RESPONSE TO SIMULATED HAIL DAMAGE

6.1 Introduction

As a component of plant reproduction and dispersal, seeds play an important role in crop production systems of many crops (Milosevic et al., 2010; Ventura et al., 2012). As the main form of reproductive strategy in flowering plants, seeds also ensure the species' survival and perpetuation (Rajjou et al., 2012). Seed quality is an important property of seed lots which is advantageous not only for the success of the crop but also the marketability, especially for seed industry (Milosevic et al., 2010). The attributes of seed quality are genetic, physical and physiological in nature. These include seed health (disease status), viability, vigour, moisture content, seed colour, shape and size (George, 1999; Kerr, 2009; Bishaw et al., 2012). However, in order to accomplish convenience of seed selection, cob health and size as well as discriminative threshing based on seed position on the cob (seed size) has been employed (Louette and Smale, 2000). These strategies reportedly enhance seed quality (Msuya and Stefano, 2010) and increase yield with ~43.2% (Louette and Smale, 2000).

As traditionally observed in seed selection based on the seed position on the cob, seeds on proximal position on the cob are generally larger than those from distal positioned seeds (Louette and Smale, 2000). This is attributed to the fact that from the cob base to the tip there is a decrease of space which affects seed size and performance, provided seeds tend to compress against each other on the cob depending on the space available (Pommel et al., 1995). In terms of seed quality, it was reported by Msuya and Stefano (2010) that large proximal seeds germinated faster and produced vigorous seedlings compared to small distal seeds. Similarly, and Pommel et al. (1995) reported larger seeds to have early emergence and seedling development than smaller seeds. Therefore, distal seeds are traditionally discriminated also due to high vulnerability to fungi and insect pest infestations as the husk may uncover the seeds and expose them to unfavourable consequences (Msuya and Stefano, 2010).

Even though seed selection may enhance seed quality, this seed property in most crops is vulnerable to defoliation from biotic and abiotic factors. However, the response may be subject to defoliation level, plant growth stage (Hicks et al., 1977; Vasilas and Seif, 1986), genotype and environmental conditions (Vasilas and Seif, 1986). It was reported that different defoliation treatments had no effect on germination percentage and rate. However, maternal environment had an effect on germination (Tollenaar and Daynard 1987; Heidari 2012). Kernel size reduction due to defoliation is the main reason for poor germination in seed quality (Vasilas and Seif, 1985a; Vasilas and Seif, 1986). This may be attributed to the fact that defoliation reduces grain filling resources such as sucrose supply to seed development (Singh and Nair, 1975; Kopture et al., 1996). Therefore, diminished amounts of assimilates in seeds results in poor germination.

Previous studies have reported on the effect and response of crops and seeds to defoliation as a form of simulated hail damage. Seed quality response to defoliation can be affected by growth stage at which plants were defoliated, level of defoliation, genotype and the environmental conditions. The detrimental effects of defoliation are exacerbated at reproductive stages of maize such as grain-fill (Vasilas and Seif, 1986). Elsewhere, Kopture et al. (1996) argued that defoliation had no significant influence on seed quality. Heidari (2012) reported that germination vigour indices such as seedling length were not influenced by defoliation even though seed vigour, root and seedling length responded positively to defoliation. Since low quality of seeds and seedling vigour in different crops is generally related with lower subsequent yields (Gelmond et al., 1978), it is vital that management practices adopted during seed production have no compromising consequences on seed quality.

Inadequate research efforts have been dedicated to studying hail damage effects on seed quality of maize progeny. More research is needed to determine resilience of maize cultivars to defoliation under different management practices such as environment and seed selection. It is also important to determine which genotypes, plant population densities and at which stages of development is maize seed quality vulnerable or resistant to hail damage. The aim of this study was to determine the interactive effect of simulated hail damage and plant density on maize seed quality.

6.2 Results and Discussion

6.2.1 Thousand grain mass

There were significant effects ($P<0.05$) of hail damage, cultivar, position on the cob and site on one thousand grain mass (1000 GM). Siahkouhian (2012) also reported that cultivars had and influence on 1000 GM. One thousand grain mass was shown to decrease from control (no hail damage) to hail damage at V7 and VT, respectively. For cultivars, 1000 GM was highest for SC701, MMP and ZS, respectively. With respect to BRGs, 1000 GM was higher for seed produced at Baynesfield than Swayimane with proximal seeds being heavier than distal seeds. The interaction of plant density, hail damage, and cultivar was significant ($P=0.007$) for 1000 GM (Table 6.1). The SC701 variety responded positively to high plant density and hail damaged imposed at growth stage V7.

6.2.2 Tetrazolium test

The individual experimental factors (Site, Position, Hail, Density and Cultivar) had no significant effect on seed viability based on the tetrazolium test. However, their interactions were significant including the five way interaction (Site*Position*Hail*Density* Cultivar). This suggested that seed viability is the outcome of interactive processes rather than individual factors. The results of this study (Table 6.1) showed that the most viable cultivar was SC701 while ZS was the least viable. Moreover, plant population density that yielded highly viable seeds was the highest one and least from lowest plant density. However, hail damage at VT resulted in viable seeds than no hail damage control.

Table 6.1: The interactive effect of hail damage with cultivar and plant density on seed quality and seedling vigour indices.

Hail Damage	Cultivar	Plant Density	1000 GM (g)	TZ-test (%)	GVI	Seedling Length (mm)	Shoot Length (mm)	Dry Mass (g)	Protein (µg/g)
CONTROL	SC701	High	450.940	91.250	53.540	171.810	86.480	0.314	0.167
		Moderate	456.320	96.250	45.480	202.190	99.520	0.268	0.159
		Low	438.200	89.480	46.230	213.250	101.830	0.258	0.161
	MMP	High	458.480	88.120	47.440	216.770	105.720	0.283	0.157
		Moderate	402.360	89.580	47.940	209.600	107.080	0.271	0.145
		Low	412.950	85.620	40.660	213.250	105.730	0.404	0.165
	ZS	High	391.630	87.710	50.290	203.380	102.900	0.253	0.167
		Moderate	409.850	82.080	48.820	235.770	109.850	0.193	0.154
		Low	468.430	89.580	44.840	232.060	98.120	0.340	0.172
V7	SC701	High	479.310	92.500	46.440	211.770	102.680	0.317	0.158
		Moderate	394.970	82.400	57.870	225.990	118.380	0.263	0.165
		Low	476.840	87.920	49.970	179.480	91.250	0.339	0.156
	MMP	High	403.480	84.380	45.610	160.500	86.750	0.289	0.160
		Moderate	445.420	85.420	49.130	205.540	99.150	0.305	0.160
		Low	389.630	83.540	46.490	186.480	91.870	0.244	0.161
	ZS	High	393.570	84.580	42.230	201.120	113.040	0.277	0.170
		Moderate	346.720	81.460	40.800	215.100	94.750	0.218	0.138
		Low	435.840	86.880	42.800	206.290	96.750	0.314	0.150
VT	SC701	High	404.460	85.420	44.930	209.400	104.400	0.281	0.151
		Moderate	450.350	86.670	54.940	175.150	93.850	0.291	0.149
		Low	419.590	91.040	39.110	199.440	105.500	0.309	0.168
	MMP	High	424.570	92.290	46.270	207.900	99.710	0.269	0.135
		Moderate	408.380	91.250	49.470	215.470	117.040	0.259	0.160
		Low	401.530	91.880	46.230	195.500	105.370	0.340	0.179
	ZS	High	387.080	89.380	49.200	171.470	88.290	0.153	0.151
		Moderate	379.490	88.750	54.380	185.820	93.170	0.285	0.154
		Low	387.730	85.620	45.070	202.500	107.870	0.279	0.148
F.Pr			0.007	0.049	0.030	0.040	0.002	0.010	0.008
LSD			57.121	7.243	6.501	34.195	15.807	0.070	0.016
CV			16.900	10.200	17.100	21.000	19.400	37.900	12.500

6.2.3 Standard germination test

There was a highly significant effect (P<0.001) of position on the cob, plant density and site on maize germination over seven days. Similar to Pommel et al. (1995), small distal seeds had low rate of emergence than large proximal seeds. This poor emergence may be attributed to higher chances of pericarp damage on the distal small seeds in addition to size. The pericarp will be mostly damaged when the cob is not well covered by the husk which is highly likely in the cob tip. These experimental factors (position on the cob, site and density) also showed a significant interaction (P<0.05) on seed germination of maize (Figure 6.1). For Baynesfield, moderate plant density and proximal seeds had the highest germination rate. Heidari (2013) argued that seed germination capacity may be affected by the environment of the maternal plant. Among other environmental factors that plants in this study were exposed to are plant defoliation due to simulated hail damage as well as plant density induced microclimate and different environments.

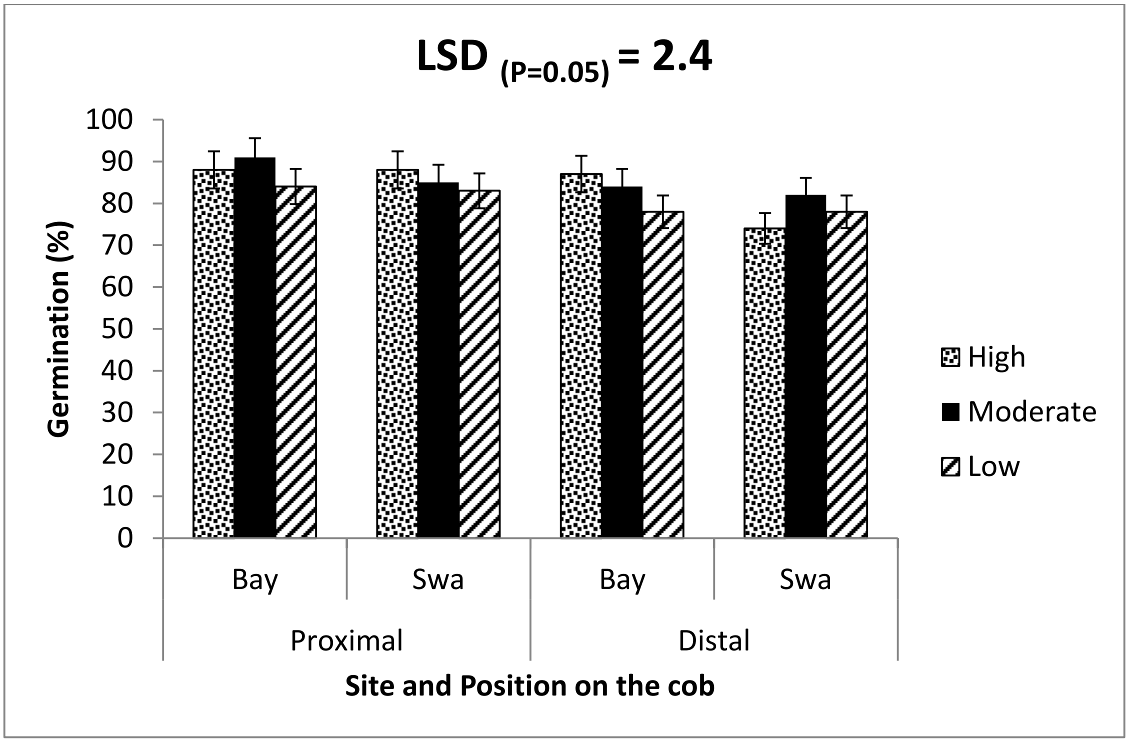

Figure 6.1: Germination response to the interaction of plant density, site and seed position on the cob.

Even though the cultivars did not have any significant effect (P>0.05), there were significant differences (P<0.05) over the period of seven days in terms of germination percentage (Figure 6.2). Germination scores on day one showed similarities between MMP and ZS. However, on day two the similarities were among cultivar SC701 and MMP. Moreover, on day four all the cultivars performed at the same level of germination. Finally, from day five, MMP started to out–perform the other cultivars in terms of germination. Even though the lowest in the beginning of germination period, MMP had the highest germination percentage on the final day of germination. However, overall cultivar SC701 had the highest rate over the period of seven days followed by MMP and then ZS.

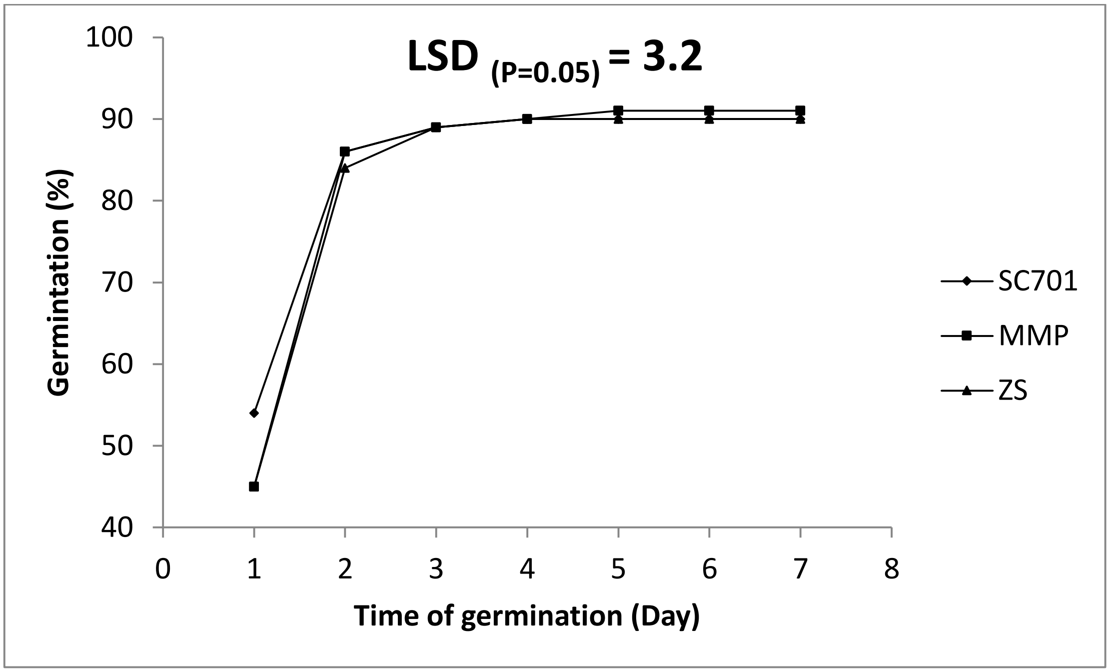

Figure 6.2: The rate of germination over the period of seven days in different cultivars.

In this study, there was no significant influence (P>0.05) of hail damage on germination. However, in another study, the only effect (P<0.05) of defoliation was decreased seed size which enhanced reduced germination (Vasilas and Seif, 1986). Pommel et al. (1995) further alluded that seedlings resulting from larger seeds were larger than smaller seeds at the same stage. This was attributed to the reduction in sucrose supply to the developing seed which is vital for seedling development (Singh and Nair, 1975). Similarly, in this study the distal seeds from both sites showed germination at lower range than the proximal seeds which were bigger compared to distal seeds (Figure 6.3). According to Lopez-Castaneda et al. (1996), the embryo that the larger seed commonly contains is larger and consequently increases chances of germination. Seed size and sucrose for the developing seedling may have led to this trend which concurs with Vasilas and Seif (1986). On the other hand, even though there is a direct relationship between seed reserves which are available for germination and seedling growth, these may be independent of seed size (Pommel, 1990). Another factor that contributes to more reserves being converted into seeds is high leaf area which intercepts high solar radiation especially in the absence of any defoliation (Gosse et al., 1986).

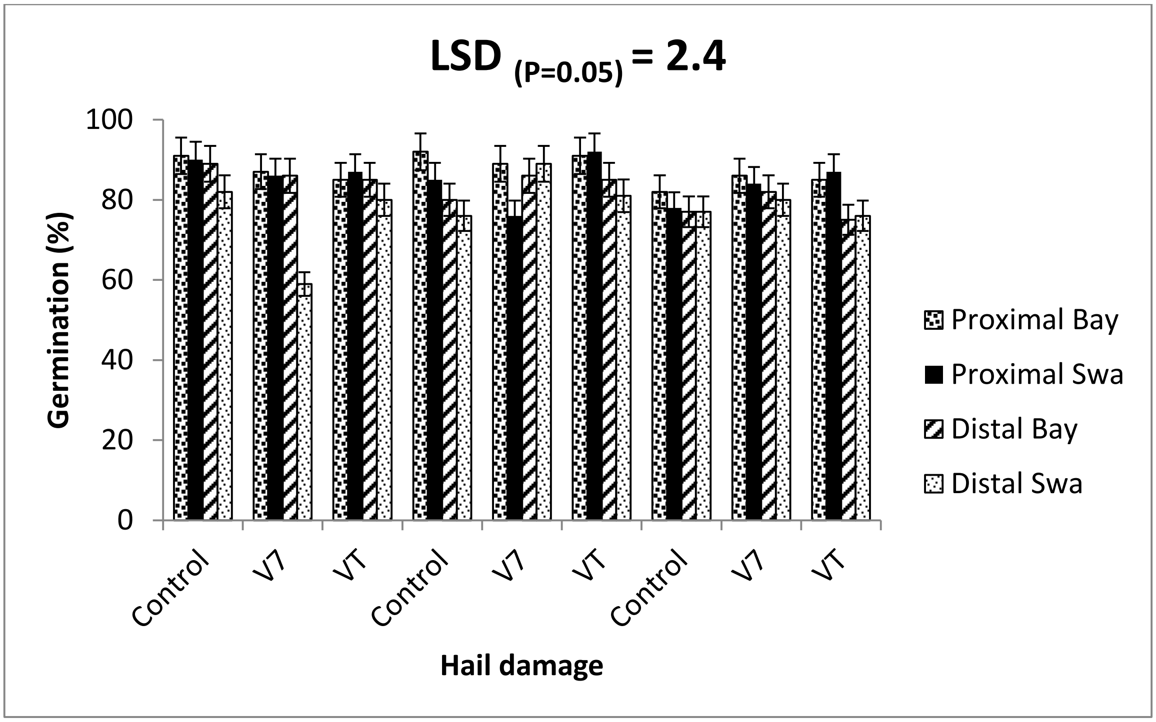

Figure 6.3: The effect of the interaction between hail damage, seed position on the cob(Proximal and Distal) and site [Bay (Baynsfield) and Swa (Swayimane).

It was confirmed by Msuya and Stefano (2010) that high quality seeds were found from the proximal than distal seed position which results in low yield. The authors further alluded that the distal seeds on maize cob are highly exposed to fungi and insect pest infestations while on the mother plant as they may be uncovered by the husk. Therefore, the physical aspect of seed quality may be compromised by not only disease infestations but also birds and insects may feed on the crop hence causing damage and inferior seed quality. Moreover, Msuya and Stefano (2010) also reported larger proximal seeds to significantly ($P<0.05$) results in vigorous seedlings based on high germination rate and consequently dry mass as opposed to distal seeds.

6.2.4 Germination vigour indices

6.2.4.1 Germination vigour index (GVI)

In addition to the significant factor interactions ($P<0.05$) with respect to germination vigour index (GVI), plant density and position on the cob were significantly different ($P<0.05$). Moderate plant density had the highest vigour index followed by high and low, respectively. Significant factor interaction included Cultivar*Density*Hail (Table 6.1). It is evident that when cultivar SC701 at moderate population density was hail damaged at V7 it had the highest GVI. However, when the same cultivar is at low population density and hail damaged at VT it shows lowest GVI. Therefore, it can be concluded that V7 and moderate plant density are superior compared to VT and low plant density.

6.2.4.2 Mean germination time (MGT)

Cultivar and plant density significantly differed ($P<0.05$) for mean germination time (MGT). Moreover, there was a significant interaction ($P<0.05$) of seed position on the cob, plant density and hail damage simulation on mean germination time (Figure 6.4). Proximal seeds from plant moderate plant density when damaged at VT took the shortest time to germinate compared to same hail damage from distal position under low plant density which took longest to germinate. These results also agrees with Msuya and Stefano (2010) who showed significant differences ($P<0.025$) between distal and proximal seeds with respect to MGT. The authors further reported that proximal seeds were superior to distal seeds. This means that since the small distal seeds are associated with less vigour they will in turn result in poor vigour seedlings thus should be discriminated during seed selection and processing. Therefore, improved germination as well as seed and seedlings vigour is important in ensuring improved subsequent yields (Msuya and Stefano, 2010). In another study it was reported that there were no significant differences (P>0.05) of germination percentage and germination time from seeds of different defoliation treatments (Kopture et al., 1996).

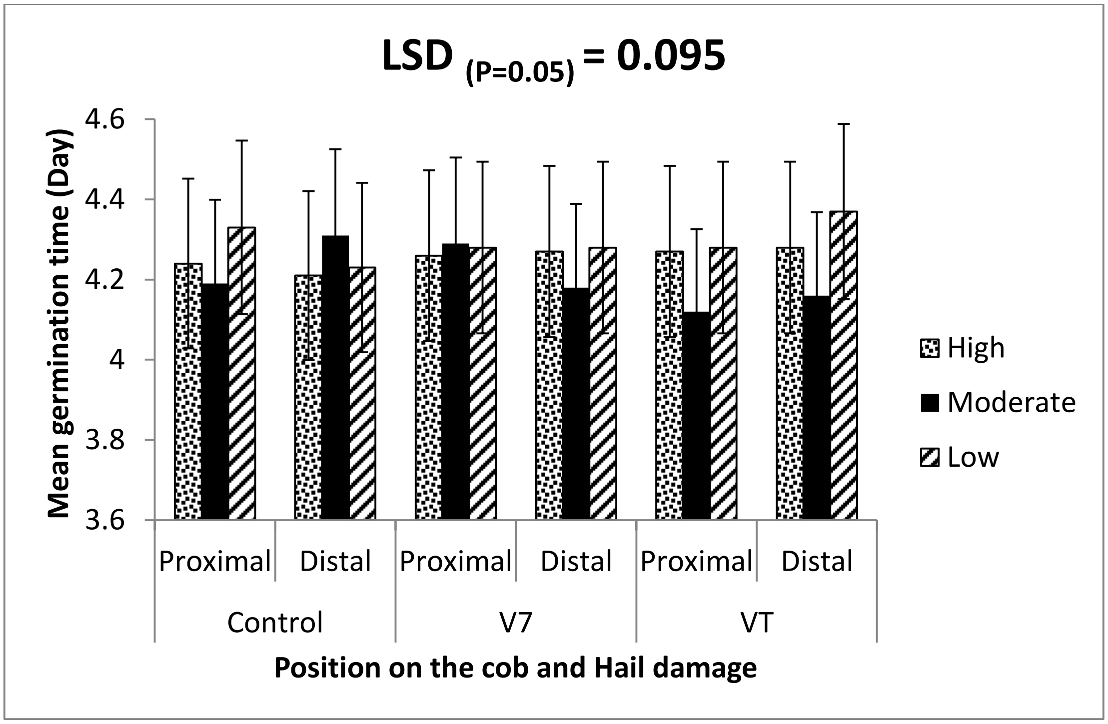

Figure 6.4: Mean germination time in response to plant density, seed position on the cob and hail damage.

6.2.4.4 Seedling dry mass

There were significant differences ($P<0.05$) among plant densities, sites on seedling dry mass. Among the significant interactions ($P<0.05$) with respect to seedling dry mass includes the five way interaction of all the experimental factors on seedling dry mass. The table (Table 6.1) shows one of the significant interactions of cultivar, density and hail ($P<0.05$) that affected seedling dry mass. There is an advantage of low plant density in cultivar MMP when there is no hail damage in terms of seedling dry mass. The opposing results were expressed by ZS at high plant density when there is hail damage at VT stage. In terms of seed position on the cob, seedling dry matter content significantly ($P<0.05$) increased from proximal compared to distal seeds. Louette and Smale, 2000 also reported proximal seeds to have significantly ($P<0.05$) highly vigorous seedlings than distal seeds.

6.2.4.5 Seedling length

Plant density and hail had significant effect ($P<0.05$) on seedling length. Moreover, all five factors differently interacted to significantly affect ($P<0.05$) seedling length. Hail damage, cultivar and density significantly interacted ($P<0.05$) to influence seedling length (Table 6.1). ZS responded positively to no hail damage (control) when grown under moderate plant density rather than MMP at V7 when grown under high density with respect to seedling length.

6.2.4.6 Root length

Hail damage had significant influence ($P<0.05$) on root length. There was also a significant interaction ($P<0.05$) between cultivar and hail damage (Figure 6.5). Cultivar SC701 performed better when it was damaged at V7 while MMP and ZS could not adapt to any hail damage as had longest roots as a consequence of no hail damage.

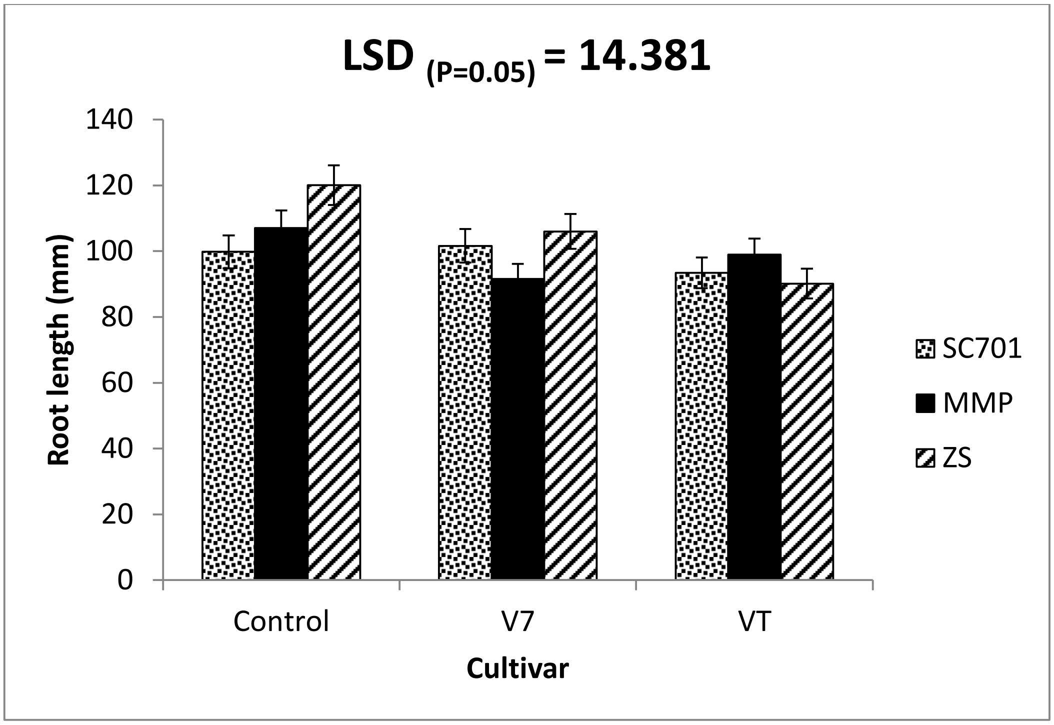

Figure 6.5: Root lengths of three maize cultivars in response to simulated hail damage. Control = no hail damage; V7 = hail damage at V7 stage of plant growth; VT = damage at VT (tasseling).

6.2.4.7 Shoot length

There was significant interaction ($P<0.05$) between hail damage, plant density and cultivar which significantly affected shoot length ($P<0.05$). SC701 under moderate plant density when damage was simulated at V7 resulted in seedlings with longest shoot length; however, the same cultivar under high plant density with no hail damage had the shortest shoots (Table 6.1).

6.2.4.8 Root:shoot ratio

Hail damage had a highly significant effect ($P<0.001$) on root to shoot root:shoot (R:S) of maize seedlings. There was a significant interaction between hail damage and plant density ($P<0.05$). Seedlings performed better in terms of R:S ratio when they were not damaged. Under plant moderate density, higher ratio occurred when damage took place at V7 (Figure 6.6). When hail damage was delayed there was the most negative effect on R:S. This means that hail damage causes seedlings to have poor root system for initial seedling establishment.

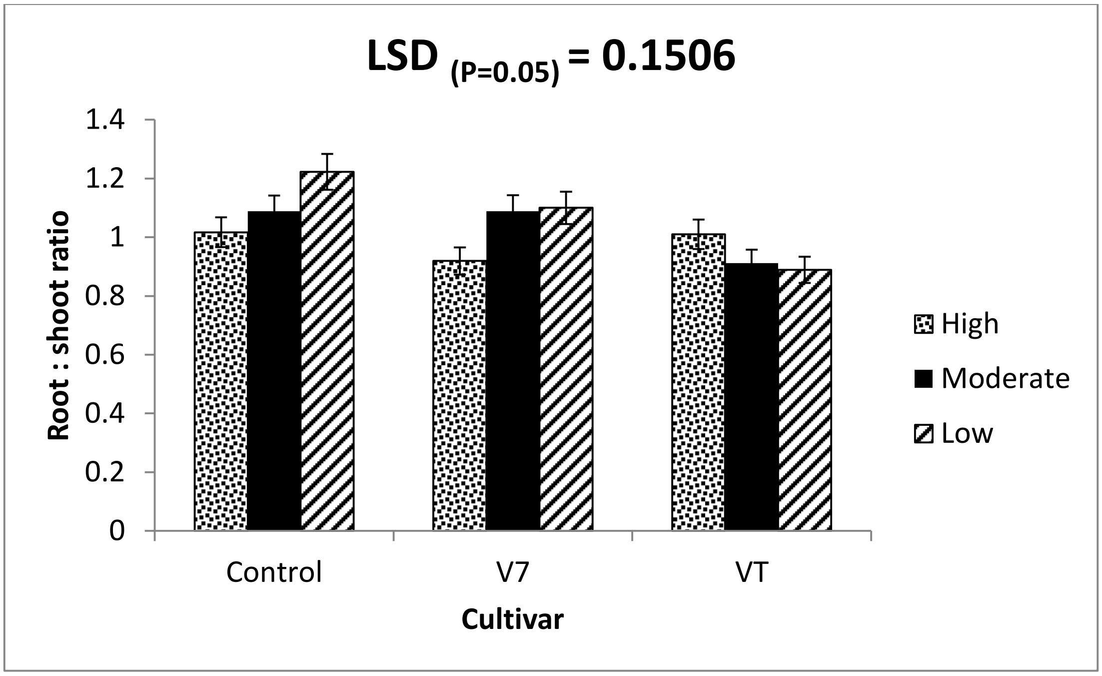

Figure 6.6: The interactive effect of plant density and hail damage on root to shoot ratio. . Control = no hail damage; V7 = hail damage at V7 stage of plant growth; VT = damage at VT (tasseling).

6.2.5 Seed proteins

There were significant ($P<0.05$) effects of plant density, hail damage and the interaction of cultivar*hail*plant density (Table 6.1) on seed protein content. This was contrary to reports that defoliation had not significant effect on protein content in plants (Siahkouhian et al., 2012; Baloyi et al., 2013). However, it should be noted that Baloyi et al. (2013) considered plant protein; the current study only considered seed protein content. For the current study, protein content decreased with the delay in hail damage. This was consistent with reports in the literature that protein concentration is more sensitive when plants are stressed at later stages of development (Fasae et al., 2009; Baloyi et al., 2013; Baroowa and Gogoi, 2015). Plants that were not subjected to hail damaged had high protein content compared to plants from hail damage treatments. The low protein content in stressed plants may be an adaptation to overcome the stress conditions (Jabasingh and Babu, 2014). However, some authors reported induced protective proteins increase as a response to stress and its tolerance (Blackman et al., 1992; Mohammadkhani and Heidari, 2008). During stress conditions the total soluble proteins increase, initially as a result of the expression of new stress proteins, which later decrease because of the severe decrease in photosynthesis (Mohammadkhani and Heidari, 2008). However, the overall effect of stress conditions to plants is a decrease in protein content (Havaux et al., 1987) due to the lack of materials provision for protein synthesis which eventually stops after decreasing drastically (Mohammadkhani and Heidari, 2008). This may explain observations in the current study whereby protein concentration was lower in hail damaged plants than non-damaged plants. Moreover, the lower accumulation of proteins in seeds is attributed to the decrease in N-accumulation and fixation to proteins (Burton et al., 1995; Singh, 2007).

Based on mean values, seed produced under low plant density had the highest seed protein content; seeds produced under moderate plan density had the least protein content. However, statistically, seed protein content from the high density treatment was statistically similar to that of seed produced under both moderate and low plant densities (Table 1). The maize cultivar that was better adapted to hail damage according to seed protein content was SC701 with poor adaptation from ZS. Although the three way interaction (Density*Hail Damage*Cultivar) was significant ($P<0.05$), cultivars alone did not vary significantly in terms of seed protein content. These results were consistent with reports by Tudsri (1986) and Riccardi et al. (1998) that cultivars did not have an effect on protein content.

6.3 Conclusion

Production environment has an effect on subsequent seed quality. Seed quality of maize cultivars indicates that plants were more resilient to hail damage at V7 or no hail damage under high plant density. While farmers often consider issues of variety selection and planting density as separate, this study showed that seed quality of maize is the sum total of the interaction of these factors and the production environment. Optimum conditions are required for seed production as shown by the superior seed quality for seeds produced at Baynesfield relative to seed produced at Swayimane. Cultivar SC701 had the highest viability (germination), vigour and protein content. The cultivar showed resilience to hail damage at V7 or no hail damage and performed well at high population density. In addition to these factors, seed selection based on the position on the cob is also important. Selecting distal seeds would result in seeds of higher quality than proximal seeds. This could also be a function of seed size as distal seeds were smaller than proximal seeds. Farmers should consider variety selection, plant population density, environment and seed position on the cob when selecting seeds.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

According to the findings of this study, hail damage reduced maize cob mass (Figures 5.18 and 5.19). These results concur with Legwaila et al. (2013) who also reported a significant reduction in cob mass with delayed defoliation. Particularly during grain filling, there is high sensitivity to reduced photosynthetic leaf area with negative consequences on production of photoassimilates to seed development (Trappeniers et al., 1992; Borras et al., 2004). Defoliation at a later stage of plant development (VT) significantly reduced LAI compared to when defoliation occurred earlier (V7) and no defoliation, respectively. Contrary to the negative impact of defoliation at a later stage of crop development (Legwaila et al., 2013), it was reported that plants have an ability to recover from defoliation when damaged at vegetative stage (Gazzoni and Moscardi, 1998) and this can be related to seed size as the selection pressure. Even though simulated hail damage had no significant effect on seed mass, the control (no hail damage) had high seed mass compared to hail damage (V7 and VT, respectively). These results are in line with (Heidari, 2013) and this proves that hail damage has a detrimental effect on seed size. In hail damaged treatments, the lower seed mass was attributed to the loss of photosynthetic leaf area (Kopture et al. 1996) responsible for translocation of the photo-assimilates to the developing seed. Elsewhere, Barimavandi et al. (2010) and Polat et al. (2011) reported that there was a significant reduction of grain yield components due to defoliation. Similar to this study, Malone and Calviness (1985) Erbas and Baydar (2007) also found plants to have considerable yield losses with delayed hail damage. Plant tolerance to hail damage when they are still young is enhanced by the fact that the growing point at that stage is below the ground level and grain yield reduction is relatively insignificant (Lee, 2007). Moreover, the current study has also established that there were highly significant differences ($P<0.001$) between cultivar, site, seed position on the cob and the interaction between cultivar and site on the seed mass. The proximal seeds had high seed mass than distal seeds and the highest seed mass was recorded for SC701 and lowest for MMP cultivars. In terms of the environment, Baynesfield produced heavier seeds than Swayimane (Figure 5.22).

In order to verify the quality of maize seeds in relation to the performance in the field as well as yield components, it was necessary to measure various seed vigour and viability parameters in the lab. There was a highly significant effect ($P<0.001$) of position on the cob, plant density and site on maize germination over seven days. Similar to Pommel et al. (1995), small distal seeds had low rate of emergence than large proximal seeds. These experimental factors (position on the cob, site and density) also showed a significant interaction ($P<0.05$) on seed germination of maize (Figure 6.1). For Baynesfield, moderate plant density and proximal seeds had the highest germination rate. Similar to this study, Heidari (2013) argued that seed germination capacity may be affected by the environment of the maternal plant. Among other environmental factors, in addition to site, that plants in this study were exposed to are plant defoliation due to simulated hail damage as well as plant density induced microclimate.

Moreover, this study shows that the effect of hail damage was not significant ($P>0.05$) with respect to germination. However, in another study, the only effect ($P<0.05$) of defoliation was decreased seed size which caused reduced germination (Vasilas and Seif, 1986). Pommel et al. (1995) further alluded that seedlings resulting from larger seeds were larger than those from smaller seeds at the same stage. This was attributed to the reduction in sucrose supply to the developing seed which is vital for seedling development (Singh and Nair, 1975). Similarly, in this study the distal seeds from both sites showed germination at lower range than the proximal seeds which were bigger compared to distal seeds (Figure 6.3). According to Lopez-Castaneda et al. (1996), the embryo that the larger seed commonly contains is larger and consequently increases chances of germination. Seed size and sucrose for the developing seedling may have led to this trend which concurs with Vasilas and Seif (1986). On the other hand, even though there is a direct relationship between seed reserves which are available for germination and seedling growth, these may be independent of seed size (Pommel, 1990). Another factor that contributes to more reserves being converted into seeds is high leaf area which intercepts high solar radiation, especially in the absence of any defoliation (Gosse et al., 1986) and this is in line with the findings of this study.

It was also reported by Msuya and Stefano (2010) that high quality seeds were found from the proximal than distal position on the cob which was attributed to high exposure to birds, fungi and insect pest infestations while on the mother plant due to opening of the husk. Larger proximal seeds had significantly ($P<0.05$) vigorous seedlings based on high germination rate and consequently dry mass as opposed to distal seeds (Msuya and Stefano, 2010). Moreover, there was a significant interaction ($P<0.05$) of seed position on the cob, plant density and hail damage simulation on mean germination time (MGT) (Figure 6.4). Proximal seeds from moderate plant density when damaged at VT took the shortest time to germinate compared to similar hail damaged seeds from distal position under low plant density which took longest to germinate. These results also agree with Msuya and Stefano (2010) who showed significant differences ($P<0.05$) between distal and proximal seeds with respect to MGT. This suggests that since the small distal seeds are associated with less vigour they will in turn result in seedlings with poor vigour and plants thus should be discriminated during seed selection and processing.

Seed quality is not limited to only germination capacity and vigour indexes but also seed nutritional composition. Among the biochemical processes that are affected by stress in plants is protein synthesis (Fresneau *et al*., 2007) and in this study hail damage was the stress that was induced to maize plants. Protein serves as the source of N for the germinating seeds (Clore and Larkins, 1998). The storage proteins supply the embryo with amino acids during germination to support the germinating seedling growth after it has been degraded (Torrent et al., 1989). In maize seeds the association between protein content and germination as well as vigour is direct (Munamava et al., 2004). The proteins nutritionally and functionally affect the overall seed quality and technological performance (Duranti and Gius, 1997). According to previous studies, defoliation decreased the concentration of seed protein (Ibrahim et al., 2013) and this decrease might have been due to the decrease in LAI (Baroowa and Gogoi, 2015). The results of this study agree with these previous findings.

The prevailing conditions in the field that maize crops are exposed to during the process of seed production has a significant influence on seed quality. The study found that not only the environment is important but there are also significant genotype and environmental interactions in seed response to hail damage. Seed selection practices based on genotype, seed size and position on the mother plant are also important for success of seed production. Choosing adapted and resilient cultivars for the prevailing conditions is of utmost importance to ensure success of seed production and hence quality. Cultivar SC701 was the best cultivar in coping with hail damage. It was also established from this study that proximal seeds from maize, which are commonly relatively large, have high seed quality. Therefore, in addition to ear selection, selective threshing of the ears with the intention of avoiding distal seeds can be useful to improve seed quality of maize. Baynesfield environment was optimum for seed production under hail damage. Crop management manipulation by varying plant population was found to be important.

Another environmental factor such as plant density played an important role in seed quality response to hail damage. Seeds from high plant density had superiour quality. Moreover, seed quality may be unaffected if hail damage is experienced at an early stage of development such as V7. However, based on the results of the Tetrazolium Test, seeds produced at Swayimane and subjected to hail damage at VT were dormant. This is because while the TZ test confirmed their viability, they failed to germinate, suggesting dormancy. These results prove that it is important to do several seed quality tests before concluding. The findings of this study show that hail damage influences maize physiology, growth, yield components and seed quality. The findings of this study can also be used in selecting planting dates in maize production systems in order to mitigate hail damage effects.

While farmers often decide on the individual factor of production and treat them as mutually exclusive, it was shown in this study that seed quality of maize is significantly affected by the interaction of hail damage, plant density, cultivar, environment and the position of seeds on the cob. Therefore, farmers should not treat the factors of maize seed production as mutually exclusive. From the results of this study, farmers can make iformed management decisions when growing maize for seed production. Farmers from hail prone areas can select cultivar SC701, high plant density when growing their maize and select seeds from the proximal part of the cob to use for the subsequent season. The findings of this study can be used to relate traditional systems of maize production in terms of selecting strategies to mitigate hail damage effects of climate change. Further research can still be done to select for and come up with hail tolerant cultivars of maize and other important food security and industrial crops and formulate climate change adaptation strategies. This is important especially since there is a need for sustainable solutions to climate change. More research is still needed in order to verify the effect of hail damage on other agronomic and industrial crops where hail damage can be imposed at all crop development stages in order to establish which stage of development is more sensitive to hail damage.

Even though progress has been made in terms of research with respect to effects of defoliation on crop performance especially yield and yield components, progress is still required on the seed quality response to hail damage. This research gap has been explored to answer the question of simulated hail damage on maize seed quality. However, as much as the current research plays an important role in contributing to the body of knowledge, there is still a need to address the issue of seed quality in response various climate change induced environmental conditions such as hail storms on more than just the physiological seed quality and seed protein content. More research questions may be answered on biochemical, genetical and physiological stress indicators and mechanisms.

REFERENCES

Abendroth, L. J., Elmore, R. W., Boyer, M. J. and Marlay, S. K. 2011. Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Abuzar, M. R., Sadozai, G. U. Baloch, M. S. Baloch A. A. , Shah I. H. , Javaid T.and Hussain N. 2011. Effect of plant population densities on yield of maize. J. Anim. Plant Sci. 21: 692-695.

Adebisi, M. A. and Ojo, D. K. 2001. Effect of genotype on soybean quality development under West African rainfed conditions. Pertanika. J. Trop. Agric. Sci, 24: 139-145.

Adebisi, M. A., Kehinde, T. O., Porbeni, J. B. O., Oduwaye, O. A., Biliaminu, K. and Akintunde S. A. 2013. Seed and seedling vigour in tropical maize inbred lines. Plant Breed. and Seed Sci. 67: 87-102.

Aguilar-Benitez, G., Pena-Valdivia, C. B., Vega, J. R., Castro-Rivera, R. and Ramirez-Tobias, H. M. 2014. Seed germination and early root growth in common bean and maize landraces and improved cultivars at different water stress levels. International Journal of Applied Science and Technology, 4: 118-127.

Akinnuoye, D. B. 2013. Interactive effects of weeding regimes and seed shapes on growth, yield and nutrient components of SC701 green mealies during summer and winter planting seasons under rain-fed condition. MSc Dissertation. University KwaZulu-Natal, South Africa.

Alimohammadi, R. and Azizov, I. 2011. Defoliation effects on yield and yield components of sunflower cultivars (*Helianthus annuus* L.). Int. J. of AgriScience, 1: 316-316.

Amanullah, R., Khattak, A. and Khalil, S. K. 2009. Effect of plant density and N on phonology and yield of maize. J. Plant Nutr. 32:246-260.

Amin C., Brinis L. 2013. Effect of seed size on germination and establishment of vigorous seedlings in durum wheat (*Triticum durum* Desf.). Advances in Environmental Biology, 1: 77–81.

Anda, A., Burucs, Z., Loke, Z. and Decsi, E. K. 2002. Effects of hail on evapotranspiration and plant temperature of maize. J. Agron. Crop Sci., 188: 335-341.

Armbrust, D. V., Paulsen, G. M. and Ellis Jr., R. 1974. Physiological responses to wind- and sandblast-damaged winter wheat plants. Agron. J. 66: 421-423.

Association of Official Seed Analysts (AOSA). 2002. Seed vigor testing handbook. Las Cruces (NM): Contribution No. 32.

Baloyi, B. M., Ayodele, V. I. and Addo-Bediako, A. 2013. Effects of leaf harvest on crude protein and mineral contents of selected early maturing lines of lablab (*Lablab purpureus*). African Journal of Agricultural Research, 8: 449-453.

Barimavandi, A. R., Sedaghathoor, S. and Ansari R. 2010. Effect of different defoliation treatments on yield and yield components in maize (*Zea mays* L.) cultivar of S.C704. AJCS 4: 9-15.

Baroowa, B. and Gogoi, N. 2015. Changes in plant water status, biochemical attributes and seed quality of black gram and green gram genotypes under drought. International Letters of Natural Sciences, 42: 1-12.

Bartolo, M. E., Schwartz, H. F. and Schweissing, F. C. 1994. Yield and growth response of onion to simulated storm damage. Hort. Sci. 29:1465-1467.

Batistella, F., Vitti Moro, F. and De Carvalho, N. 2002. Relationships between physical, morphological, and physiological characteristics of seeds developed at different positions of the ear of two maize (*Zea mays* L.) hybrids. Seed Science and Technology, 30(1): 97-106.

Battaglia, M. L. 2014. Corn (*Zea mays* L.) yield response to defoliation at different row widths. MSc Dissertations, University of Kentucky, Lexington, Kentucky, Pp 121.

Bishaw, Z., Struik, P. C. and Van Gastel, A. J. G. 2012. Farmers' seed sources and seed quality: Physical and physiological quality. J.Crop Improv. 26, 655-692.

Blackman, S. A, Obendorf, R. L. and Leopold, A. C. 1992. Maturation proteins and sugars in desiccation tolerance of developing soybean seeds. Plant Physiol. 100: 225-230.

Bore, J. K., Cheserek, B. C. Ng'etich, W. K. and Yegon, S. K. An analysis of the incidences of hail damage in tea areas of Kenya. Tea, 32: 15-20.

Borras, L., Slafer, G. A. and Otegui, M. E. 2004. Seed dry weight response to source-sink manipulations in wheat, maize and soybean: a quantitative reappraisal. Field Crop Res. 86: 131-146.

Botzen, W. J. W., Bouwer, L. M. and van den Bergh, J. C. J. M. 2010. Climate change and hailstorm damage: Empirical evidence and implications for agriculture and insurance. Resour. and Energy Econ. 32: 341-362.

Bradford, M. M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein–dye binding. Analytical Biochemistry. 72: 248-254.

Burmood, D. T. 1971. Effects of simulated hail damage on soybeans, (Glycine max (L.) Merrill) as influenced by row spacing and variety. PhD dissertation, Iowa State University, Ames, Iowa. Pp 147.

Burton, J. W. Israel, D. W., Wilson, R. F. and Carter, T. E. 1995. Effect of defoliation on seed protein concentration in normal and high protein lines of soybean. Plant and soil, 172: 131-139.

Cardwell, V. B. 1982. Fifty years of Minnesota: corn production source of yield increase. Agron. J., 74: 998-990.

Changnon, S. A. 1977. The scales of hail. J. Appl. Meteorol. 16: 626- 648.

Cline, W. R. 2007. Global warming and agriculture: Impact estimates by country. Centre for Global Development, Peterson Institute for International Economics.

Clore, A. M and Larkins, B. A. 1998. Protein quality and its potential relationship to the cytoskeleton in maize endosperm. J. Plant Physiol., 152: 630-635.

Conley, S. P., Abendroth, L., Elmore, R., Christmas, E. P. and Zarnstorff, M. 2008. Soybean seed yield and composition response to stand reduction at vegetative and reproductive stages. Agron. J. 100: 1666-1669.

Dahmardeh, M. 2011. Effect of plant density and nitrogen rate on PAR absorption and maize yield. Am. J. Plant Physiol. 1-6.

Dewi, P. P. 2009. Climate change impacts on tropical agriculture and the potential of organic agriculture to overcome these impacts. As. J. Food Ag-Ind. S10-S17.

Doebley, J. F. 2004. The genetics of maize evolution. Annu. Rev. Genet., 38: 37-59.

Dolfini, S., Consonni, G., Viotti, C., Dal Pra, M., Saltini, G., Giulini, A., Pilu, R., Malgioglio, A. and Gavazzi, G. 2007. A mutational approach to the study of seed development in maize. J. Exp. Bot. 58: 1197-1205.

Dredge, R. D. 2013. Final area planted and crop production figures of commercial maize, sunflower seed, soya beans, groundnuts and sorghum for 2013. Available from: www.daff.gov.za/crop estimates. Accessed: 2 March 2015.

du Plessis, J. 2003. Maize production. Available from: www.nda.agric.za/publications. Accessed: 1 March 2015.

Duranti, M and Gius, Cristina. 1997. Legume seeds: protein content and nutritional value. Field Crops Research, 53: 31-45.

Duval, J. and NeSmith, D. 2001. Difference in seed coat thickness between the cultivars. Resistance to gas diffusion through the seed coat and hilum of watermelon (*Citrullus lanatus* Matsum and Nakai). Proc. Fla. State Hortic. Soc. 114: 323-326.

Edwards, J. T., Purcell, L. C. and Vories, E. D. 2005. Light interception and yield potential of short-season maize (*Zea mays* L.) hybrids in the midsouth. Agron. J. 97: 225-234.

Elias, S, Garay, A., Schweitzer, L. and Hanning, S. 2006. Seed quality testing of native species. Native Plants Journal, 7:15-19.

Elias, S. 2006. Seed quality testing. In: Basra, A.S. Handbook of seed science and technology. Food products press, New York. Pp 561-601.

Erbas, S. and Baydar, H. 2007. Defoliation effects on sunflower (*Helianthus annuus* L.) seed yield and oil quality. Turk. J. Biol. 31: 115-118.

Eubanks, M. W. 2001. The mysterious origin of maize. Econ. Bot. 55: 492-514.

FAO. 2012. Statistical databases and data-sets, Food and Agriculture Organization of the United Nations. Available from: http://faostat3.fao.org/home/index.html. Accessed: 05 March 2015.

FAOSTAT. 2012. FAO Statistical Yearbook 2012. Available at: http://faostat.fao.org. Accessed: 5 March 2015.

Farnham, D. E. 2001. Row spacing, plant density, and hybrid effects on corn grain yield and moisture. Agron. J. 93: 1049-1053.

Farnia, A. and Mansouri, M. 2014. Effect of plant density to yield and yield components of maize (*Zea mays* L.) cultivars. Bull. Env. Pharmacol. Life Sci. 3: 123-127.

Fasae, O. A., Adu, F. I., Aina, B. J. A. and Elemo, K. A. 2009. Effects of defoliation time of maize on leaf yield, quality and storage of maize leafs as dry season forage for ruminant production. Revista Brasileira de Ciencias Agrarias, 4: 353-357.

Fresneau, C., Ghashghaie, J. and Cornic, G. Drought effect on nitrate reductase and sucrosephosphate synthase activities in wheat (*Triticum durum* L.): Role of leaf internal CO2. J. Exp. Bot. 10: 1-10.

Gay, J. P. and Bloc, D. 1984. Determination of the components of grain yield. In: A. Gallais (ed.), Corn Physiology 181-192.

Gazzoni, D. L. and Moscardi, F. 1998. Effect of defoliation levels on recovery of leaf area, on yield and agronomic traits of soybean. Pesq. Agropec. Bras. 33: 411-424.

Gelmond, H., Luria, I., Woodstock, L. W. and Perl, M. 1978. The effect of accelerated ageing of sorghum seeds on seedling vigour. J. Exp. Botany, 29: 489-495.

George, R. A. T. 1999. Vegetable seed production. CAB International. Rome. Pp 96-98, 196-201.

Ghassemi-Golezani, K. 1992. Effects of seed quality on cereal yields. PhD Dissertation. University of Reading, UK.

Ghassemi-Golezani, K. Tajbakhsh, K. and Raey, Y. 2011. Seed development and quality in maize cultivars. Not. Bot. Hort. Agrobot. Cluj. 39: 178-182.

Ghassemi-Golezani, K., Khomari, S., Dalil, B., Hosseinzadeh-Mahootchy, A. and Chadordooz-Jeddi, A. 2010. Effects of seed aging on field performance of winter oil-seed rape. J Food Agric Environ, 8:175-178.

Gosse, G., Varletgrancher, C., Bonhomme, R., Chartier, M., Allirand, J. M. and Lemaire, G. 1986. Maximum dry-matter production and solar-radiation intercepted by a canopy. Agronomie, 6: 47-56.

Gustavo, A.M., G.C. Alfredo and M.E. Otegui. 2006. Row width and maize grain yield. Agron. J. 98: 1532-1543.

Hampton, J. G. 1995. Methods of viability and vigour testing: A critical appraisal. In: A.S. Basra (ed.). Seed Quality: Basic Mechanisms and Agricultural Implications. Food Products Press, New York.

Harris, D., Pathan, A.K., Gothkar, P. Joshi, A., Chivasa, W. & Nyamudeza, P. 2001. On-farm seed priming: using participatory methods to revive and refine a key technology. Agricultural Systems, 69, 151–164.

Hashemi, D. A. and Maraashi, E. 1993. Photosynthetic materials changes at anthesis stage and its effect on grain growth and yield components of wheat. AgriSci & Ind. J. 9: 16-32.

Hassan, A. A. 2000. Effect of plant population density on yield and yield components of eight Egyptian maize hybrids. Bull. Fac. Agric. Univ. Cairo, 51: 1-16.

Havaux, M., Canaani, O. and Malkin, S. 1987. Inhibition of photosynthetic activities under slow water stress measured in vivo by photoacoustic method. Physiol. Plant, 70: 503-510.

Heidari, H. 2012. Effect of defoliation intensity on maize yield, yield components and seed germination. Life Science Journal, 4: 1594-1598.

Heidari, H. 2013. Yield, yield components and seed germination of maize (*Zea mays* L.) at different defoliation and tassel removal treatments. Philipp Agric. Scientist, 96: 42-47.

Hepting, L., 1990: Hail damage- how rough is the yield losses? Corn 18: 15-18.

Hicks, D. R., Nelson, W. W. and Ford, J. H. 1977. Defoliation effects on corn hybrids adapted to the northern corn belt. Agron. J. 69:387-390.

International Seed Testing Association (ISTA) Edition 2012. Adopted at the Ordinary Meeting 2011, Glattburgg, Switzerland.

Jabasingh, C. and Babu, S. S. 2014. Impact of water stress on protein content of *Zea mays* L. Journal of Academia and Industrial Research, 2: 679-682.

Jenner, C. F. 1986. End Product Storage in Cereals. In Cronshaw, J., W. J. Lucas and R. T. Giaquinta (Eds.), Phloem Transport. Plant Biology. Alan R. Liss Inc. New York. Pp 561-572.

Johansen, R. R. and Wax, L. M. 1978. Relationship of soybean germination and vigour test to field performance. Agron. J. 70: 273-276.

Johnson, B. L. 2003. Dwarf sunflower response to row spacing, stand reduction, and defoliation at different growth stages. Can. J. Plant Sci. 83: 319-326.

Kalton, R. R., Weber, C. R., and J. C. Edlredge. 1949. The effect of injury simulating hail damage to soybeans. Iowa Agr. Exp, Sta. Res. Bui. 359.

Kerr, D. S. 2009. Seed quality and the use of organic treatments to improve crop performance. MSc dissertation, Dalhousie University, Halifax, Nova Scotia. Pp 24.

Klein, R. N. and Shapiro, C. A. 2011. Evaluating hail damage to corn. Available from: www.ianrpubs.unl.edu. Accessed: 26 February 2015.

Kopture, S., Smith, C. L. and Lawton, J. H. 1996. Effect of artificial defoliation on reproductive allocation in the common vetch *Vicia sativa* (fabaceae; papilionoideae). Amer. J. of Bot. 83: 886-889.

Lauer, J. G. 1994. Hail damage to corn in the dent stage. Wisconsin Crop Manager, 1:156-157.

Lauer, J. G. 2009. Late-season hail effects on corn. Field Crops, 28: 492-69.

Lauer, J. G., Roth, G. W. and Bertram, M.G. 2004 Impact of defoliation on corn forage yield. Agron. J. 96: 1459-1463.

Lee, C. D. 2006. Reducing row width to increase yields: why it does not always work? Crop Management doi: 10.1094/CM-2006-0227-04-RV.

Legwaila, G. M., Mathowa, T. and Jotia, E. 2013. The effect of defoliation on growth and yield of sorghum (*Sorghum bicolor* (L) *Moench*) variety- segaolane. Agric. Biol. J. N. Am. 4: 594-599.

Lemons, H. 1942. Hail in American agriculture. Econ. Geogr. 18: 363-378.

Liu, X., Robinson, P. W., Madore, M. A., Witney, G. W. and Arpaia, M. L. 1999. 'Hass' avocado carbohydrate fluctuations. II. Fruit growth and ripening. Am. Soc. Hort. Sci. 124: 676-681.

Lopez-Castaneda, C., Richards, R. A., Farquhar, G. D. and Williamson, R. E. 1996: Seed and seedling characteristics contributing to variation in early vigor among temperate cereals. Crop Science, 36: 1257-1266.

Louette, D. and Smale, M. 2000. Farmers' seed selection practices and traditional maize varieties in Cuzalapa, Mexico. Euphytica 113: 25-41.

Mabhaudhi, T. and Modi, A.T. 2010. Early establishment performance of local and hybrid maize under two water stress regimes. S.Afr. J. Plant and Soil, 27: 299-304.

Maguire, J. D., 1962. Speed of germination - aid in selection and evaluation for seedling emergence and vigour. Crop Sci. 2: 176-177.

Mallett, J. B. 1993. Cultural practices. In: Maize in Natal- Agricultural production guidelines for Natal.

Malone, S. R., and Calviness, C. E. 1985. Cut-off, break over, and defoliation effect on a determinate soybean cultivar. Agron. J. 77: 585-588.

Marks, B. P. and Stroshine, R. L. 1998. Relating electrolyte leakage to shelled corn storability. Cereal Chem. 75: 651-655.

Martinez-Villaluenga, C., Penas E., Ciska, E., Piskula, M. K., Kozlowska, H., Vidal-Valverde, C. and Frias, J. 2010. Time dependence of bioactive compounds and antioxidant capacity during germination of different cultivars of broccoli and radish seed. Food Chemistry, 120: 710–716.

Mattioni, N. M., Mertz, L. M., Barbieri, A. P. P., Haesbaert, F. M., Giordani, W. and Lopes, S. J. 2015. Individual electrical conductivity test for the assessment of soybean seed germination. Sowing: Agricultural Sciences, London, 36: 31-38.

Mazvimbakupa, F., Modi, A. T. and Mabhaudhi, T. 2014. Seed quality and water use characteristics of maize landraces compared with selected commercial hybrids. Chilean J. Agri. Research 75: 13-20.

McDonald, J. M. B. 1975. A review and evaluation of seed vigour test. Proc. Assoc: Offic. Seed Anal. 65: 109-139.

McKersie. B. D., Tomes, D. T. and Yamamoto, S. l98l. Effect of seed size on germination, seedling vigor, electrolyte leakage, and establishment of bird's-foot trefoil (*Lotus corniculatus* L.). Can. J. Plant Sci. 6l: 337-343.

Milosevic M., Vujakovic, M. and Karagic, D. 2010. Vigour tests as indicators of seed viability. Genetika, 42: 103-118.

Milosevic, M. and Malesevic, M. 2004. Seed Science. Monograph. Ed. Institute for Field and Vegetable Crops and National Laboratory for Seed testing, Novi Sad, Serbia. Pp 110-114.

Milosevic, M. and Zlokolica, M. 1996. Seed vigour. Plant breeding and seed production, Novi Sad, 3: 33-43.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? Clim. Policy, 3: 233-248.

Mohammadkhani, N. and Heidari, R. 2008. Effects of drought stress on soluble proteins in two maize varieties. Turk. J. Biol. 32: 23-30.

Mondoni, A., Rossi, G and Balestrazzi, A. 2012. Understanding the molecular pathways associated with seed vigor. Plant Physiol. Biochem., 60: 196-206.

Msuya, D. G. and Stefano, J. 2010. Responses of maize (*Zea mays*) seed germination capacity and vigour to seed selection based on size of cob and selective threshing. World Journal of Agricultural Sciences, 6: 683-688.

Muasya, R. M., Lommen, W. J. M., Muui, C. W. and Struik, P. C. 2008. How weather during development of common bean (*Phaseolus vulgaris* L.) affects the crop's maximum attainable seed quality. NJAS, 56: 85-100.

Munamava, M. R., Goggi, A. S. and Pollak, L. 2004. Seed quality of maize inbred lines with different composition and genetic backgrounds. Crop Science, 44:542-548.

Muro, J., Irigoyen, I., Milition, A. F. and Lamsfus, C. 2001. Defoliation effects on sunflower yield reduction. Agron. J. 93: 634-637.

Nasir, M. 2000. The effects of different plant population on yield and yield components of different maize varieties. M. Sc. (Hons) Thesis, Dept. of Agron. KPK Agric. University, Peshawar, Pakistan.

Nasreen, S., Yasuf, M., Akbar, Mohammad, S. and Malik, M. A. 2002. Study of seed dormancy mechanisms, causes and control. Asian J. Plant Sci. 1: 210-212.

Ngaira, J. K. W. 2007. Impact of climate change on agriculture in Africa by 2030. Sci. Res. Essays, 2: 238-243.

Nielsen, R. L. 1988. Influence of hybrids and plant density on grain yield and stalk breakage in corn grown in 38 cm row width. J. Prod. Agric. 1: 190-195.

O'Keefe, K. and Schipp, A. 2009. Germination and emergence; vegetative growth; reproductive development and kernel development. In: Maize growth and development. Available from: www.dpi.nsw.gov.za. Accessed: 19 March 2015.

Odiemah, M. 1989. Quantitative inheritance of seed quality characteristics in maize (*Zea mays* L.). Cereal Res. Commun. 17:245-251.

Omara, P. 2013. Effect of seed distribution and population on maize (*Zea mays* L.) grain yield. MSc dissertation, Oklahoma State University, Stillwater, Oklahoma.

Palagyi, A. and Nemeth, J. 1996. Maize hybrid seed production by the mutual random mating of the parental components. Cereal Res. Commun. 24: 307-316.

Panobianco, M., Vieira, R. D. and Perecin, D. 2007. Electrical conductivity as an indicator of pea seed aging of stored at different temperatures. Agri. Sci. 64: 119-124.

Pearsoni, A. and Fletcher, A. L. 2009. Effect of total defoliation on maize growth and yield. Agron. New Zealand, 39: 1-6.

Penaloza, P, Ramilez-Rosales, G., McDonald, M. B. and Bennett, M. A. 2005. Lettuce (*Lactuca sativa* L.) seed quality evaluation using seed physical attributes, saturated salt accelerated aging and the seed vigour imaging system. Electronic J. Biotechn. 8: 299-307.

Perry, D. A. 1980. The concept of seed vigor and its relevance to seed production techniques. In: Hebblathwaite, P. D. (Ed), Seed Production. Butterworths, London. Pp 585-591.

Persson, T., Garcia, A., Paz, J., Jones, J. and Hoogenboom, G. 2009. Maize ethanol feedstock production and net energy value as affected by climate variability and crop management practices. Agric. Sys. 100: 11-21.

Peters, A. J., Griffin, S. C. and Vina, A. 2000. Use of remotely sensed data for assessing crop hail damage. Photogramm Eng. Rem. S. 66: 1349-1355

Polat, T., Ozer, H. and Ozturk, E. 2011. Responses of hybrid and open pollinated sunflowers (*Helianthus annuus* L.) to defoliation. Austr. J. Crop Sci. 5: 132-137.

Pommel, B., Goytino, B. and Bonhomme, R. 1995. Effects of seed size, seed position on the parent cob and parental cob size on the leaf area of maize under field conditions. Eur. J. Agron. 4: 363-369.

Protic, R., Jovin, P., Protic, N., Jankovic, S. and Jovanovic, Z. Mass of 1,000 grains in several winter wheat genotypes, at different dates of sowing and rates of nitrogen fertilizer Romanian Agricultural Research, 24:39-43.

Rajjou, L., Duval, M., Gallardo, K., Catusse, J., Bally, J., Job, C. and Job, D. 2012. Seed germination and vigor. Annu. Rev. Plant Biol. 63: 507-33.

Ranere, A. J., Piperno, D. R., Holst, I., Dickau, R., Iriarte, J. 2009. The cultural and chronological context of early Holocene maize and squash domestication in the Central Balsas River Valley, Mexico. Proc. Natl. Acad. Sci. USA, 106: 5014-5018.

Riccardi, F., Gazeau, P., de Vienne, D. and Zivy, M. 1998. Protein changes in response to progressive water deficit in maize. Plant Physiol. 117: 1253-1263.

Robertson, A. E., Munkvold, G. P., Hurburgh, C. R. and Ensley, S. 2011. Effects of natural hail damage on ear rots, mycotoxins, and grain quality characteristics of corn. Agron. J. 103: 193-199.

Saberali, S. F. 2007. Influence of plant density and planting pattern of corn on its growth and yield under competition with common Lambs quarters (*Chenopodium album* L.). Weed Biology and Management. 74: 143-152.

Sakala, W. D. and Kabambe, V. H. 2004. Maize agronomy research report, 2000-2003. Chitedze Research Station, Ministry of Agriculture Irrigation and Food Security Lilongwe, Malawi.

Salvador, R. J. 1988. Simulation of kernel development and assimilate partitioning in maize. PhD dissertation, Iowa State University, Ames, Iowa. Pp 362.

Sangakkara, U. R., Bandaranayake, P. S. R. D., Gajanayake, J. N. and Stamp P. 2004. Plant populations and yield of rainfed maize grown in wet and dry seasons of the tropics. Maydica. 49: 83-88.

Sangoi, L. 2001. Understanding plant density effects on maize growth and development: an important issue to maximize grain yield. Scie. Rural. 31: 159-168.

Schneiter, A, Jones, J. M. and Hammond, J. J. 1987. Simulated hail research in sunflower defoliation. Agron. J. 79: 431- 434.

Schneiter, A. A. and Johnson, B. L. 1994. Response of sunflower plants to physical injury. Can. J. Plant Sci. 74: 761-766.

Severini, A. D., Borras, L., Westgate, M. E. and Cirilo, A.G. 2011. Kernel number and kernel weight determination in dent and popcorn maize. Field Crops Res. 120: 360-369.

Shafi, M., Bakht, J., Ali, S., Khan, H., Khan, M. A. and Sharif, M. 2012. Effect of planting density on phenology, growth and yield of maize (*Zea Mays* L.). Pak. J. Bot. 44: 691-696.

Shafiullah Khan, M. A., Poswal M. A., Rana M. A., and Baitullah M. A. 2001. Simulation of leaf damage by artificial defoliation and its effect on sunflower (*Helianthus annuus* L.) performance. Helia 24: 145-154.

Siahkouhian, S, Shakiba, M. R., Salmasi, S. Z., Ghassemi-Golezani, K. and Toorchi, M. 2012. Defoliation effects on yield components and grain quality of three corn cultivars. International Conference on Environment, Agriculture and Food Sciences (ICEAFS'2012), Phuket (Thailand). Pp 1-4.

Sikandar, A., Ali, M., Amin, M., Bibi, S. and Arif, M. 2007. Effect of plant population on maize hybrids. J. Agric. Biol. Sci. 2: 13-20.

Singh S. P. 2007. Drought resistance in the race Durango dry bean landraces and cultivars. Agron. J. 99: 1219-1225.

Singh, R. P. and Nair, K. P. P. 1975. Defoliation studies in hybrid maize. II. Dry matter accumulation, leaf area index, silking, and yield components. J. Agric. Sci. Camb. 85: 247-254.

Sisu, M., Mircov, V. D. and Nita, S. 2011. Hail - phenomena of risk for agriculture. Research J. Agric. Sci. 43: 490-496.

Smale, M., Bellon, M. R. and Gomez, J. A. A. 2001. Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, Mexico. Econ. Deve. Cult. Change, 50: 201-225.

Smith, J. M. B. 1993. Maize yield estimation. In: Maize in Natal- Agricultural production guidelines for Natal.

Soil Classification: a Taxonomic System for South Africa. 1991. Soil Classification Working Group. Department of Agricultural Development. Pretoria, South Africa.

Sun, Q., Wang, J. and Sun, B. 2007. Advances on seed vigor physiological and genetic mechanisms. Agric. Sci. China, 6: 1060-1066.

Tartachnyk, I. and Blanke, M. M. 2002. Effect of mechanically-simulated hail on photosynthesis, dark respiration and transpiration of apple leaves. Environ. Exper. Bot. 48: 169-175.

Tartachnyk, I. I. and Blanke, M. M. 2008. Temperature, evapotranspiration and primary photochemical responses of apple leaves to hail. J. Plant Physiol. 165: 1847-1852.

Tenaillon, M. I. and Charcosset, A. 2011. A European perspective on maize history. C. R. Biologies, 334: 221-228.

Thomison, P. R. and Nafziger, E. D. 2003. Defoliation affects grain yield, protein, and oil of top cross high-oil corn. Crop Man. Online. doi: 10.1094/CM-2003-1027-01- RS.

Thornton, J. M., Powell, A. A. and Mathews S. 1990. Investigation of the relationship between seed leachate conductivity and germination of Brassica seeds. Ann. Applied. Biol. 117: 129-135.

Tollenaar, M. and Daynard, T. B. 1978. Effect of defoliation on kernel development in maize. Can. J. Plant Sci. 58: 207-212.

Tollenaar, M., Aguilera, A. and Nissanka, S. P. 1997. Grain yield is reduced more by weed interference in an old than in a new maize hybrid. Agron. J. 89: 239-246.

Torrent, M., Geli, M. I. and Ludevid, M. D. 1989. Storage-protein hydrolysis and protein-body breakdown in germinated *Zea mays* L. seeds. Planta, 180:90-9.

Trappeniers, G., Ledent, J. F., Fay, O. and Nijs, A. 1992. Effects of simulated hail damage on the yield of forage maize. J. Agronomy & Crop Sci. 168: 13-19.

Valadabadi, S. A. and Farahani, H. A. 2010. Effects of planting density and pattern on physiological growth indices in maize (*Zea mays* L.) under nitrogenous fertilizer application. J. Agric. Ext. and Rural Dev. 2: 40-47.

Vasilas, B. L. and Seif, R. D. 1986. Effect of defoliating corn inbreds on seed quality. J. Seed Technol. 10: 121-128.

Vasilas, B. L. and Seif, R. D. 1985a. Defoliation effects on two corn inbreds and their single cross hybrid. Agron. J. 77:816-820.

Vasilas, B. L. and Seif, R. D. 1985b. Pre-anthesis defoliation effects on six corn inbreds. Agron. J. 77:831-835.

Vega, C. R. C., Andrade, F. H. and Sadras, V. O. 2001. Reproductive partitioning and seed set efficiency in soybean, sunflower and maize. Field Crops Res. 72: 165-173.

Ventura, L., Dona, M., Macovei, A., Carbonera, D., Buttafava, A., Mondoni, A., Rossi, G. and Balestrazzi, A. 2012. Understanding the molecular pathways associated with seed vigor. Plant Physiology and Biochemistry, 60: 196-206.

Vieira, R. D., Penariol, A. L., Perecin, D. and Panobianco, M. 2002. Electrical conductivity and initial water content of soybean seeds. Bras. Agric. Research, 37: 1333-1338.

Visher, S. S. 1940. Weather influences on crop yields. Economic Geography, 16: 437-443.

Westgate, M. E., Forcella, F., Reicosky, D. C. and Somsen, J. 1997. Rapid canopy closure for maize production in the northern US Corn Belt: radiation-use efficiency and grain yield. Field Crops Res. 49: 249-258.

White, P. J. and Johnson, L. A. 2003. Corn: chemistry and technology, American Association of Cereal Chemists.

Widdicombe, W. D. and Thelen, K. D. 2002. Row width and plant density effect on corn grain production in the Northern Corn Belt. Agron. J. 94: 1020-1023.

Zamir, M. S. I., Ahmad, A. H., Javeed, H. M. R. and Latif, T. 2011. Growth and yield behaviour of two maize hybrids (*Zea mays* L.) towards different plant spacing. Agrono. Research in Moldova, 146: 33-40.

Zhao, J. L. Zhang, D. Y., Luo, J. H., Huang, S. L., Dong, Y. Y. and Huang, W. J. 2012. Aust. J. Crop Sci. 6:101-108.

APPENDIX

Appendix 1: Seed protein standard curve