Breeding Investigations for Development of Specialty Green Maize Hybrids

By

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for the degree of Master of Science in Plant Breeding

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Thesis Abstract

Green maize (*Zea mays* L.) provides food security and cash income to rural households in Sub-Saharan Africa (SSA). However, research on green maize varieties is scarcely reported in the literature. Consequently there is no information on suitable genetic materials (germplasm) for green maize production. Additionally there is no data regarding quality attributes of suitable hybrids, which impacts on variety development and management. Breeding investigations were therefore conducted to investigate farmers' preferences for hybrids and attributes of green maize hybrids in KwaZulu-Natal, in South Africa, and to determine combining ability for green maize traits of experimental inbred lines that were derived from an experimental population. The study also investigated the relationships between green maize traits and some desired agronomic traits; and also sought to identify specific inbred combinations (hybrids) with potential for green maize production.

A case study was conducted at Mjindi (MJD) and Ndumo (NDO) Irrigation Schemes in KwaZulu - Natal South Africa, to determine the attributes of the "ideal" hybrid, production constraints, production trends and enterprise viability. Prior to a formal survey some focus group discussions were conducted, then 64 green maize growers were interviewed using a formal questionnaire. The study indicated that the most desired consumer traits were a combination of sweet taste, long shelf life and large ears. The required attributes of the model hybrids were high grain yield potential, high selling ability, flint grain texture, white grain color, medium ear placement, thick and long ears, short maturity period, medium plant height, long shelf life and nonpopping during roasting. This study also showed that the enterprise was viable with average gross margin of about R10, 000 per ha which makes it attractive to both small and large-scale commercial farmers with implications for rural development in the second economy. Thus there is a great business potential, but lack of suitable and special hybrids appears to be the major production constraint which should be addressed by research and development.

A total of 100 advanced maize inbred lines were crossed in a line x tester mating scheme to generate 200 experimental hybrids. The hybrids with sufficient seed were evaluated for green maize and agronomic traits at three sites in KwaZulu-Natal. Large genotype x environment interaction effects were observed which was reflected by the different ranking of hybrids at each site resulting in selection of different sets of top 15 hybrids with potential for production in each environment. Only a few hybrids exhibited high performance consistently in at least two mega environments. The results showed that hybrids were highly significantly different for the green maize traits such as ear yield, ear length, single ear weight and marketability indices, and also for the agronomic traits. The difference among hybrids for marketing ability indices was attributed to the testers main effects and specific combining ability (SCA) effects. Differences between the general combining ability (GCA) of the lines and testers, and SCA effects were significant for the green maize traits. These findings suggested that the traits are governed by both additive and non-additive gene effects, respectively. Additionally observation of continuous and normal distribution of hybrids for the traits indicated that quantitative minor genes were involved and therefore the base population can be improved by selection for large ears, superior marketability index, and high single ear yield. The observed top performing hybrids were recommended for further testing at many sites. Results confirmed that the current dominant variety is not adapted to summer production conditions in the Mjindi and Ndumo areas which present opportunities for breeding programmes. Future studies should therefore aim to improve both the genetics and production economics of specialty green maize hybrids to further enhance profitability of the enterprise with positive implication for the rural economy in KwaZulu-Natal.

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Declaration

I, Qwabe Fikile Nozipho Pricilla, declare that,

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As the candidate‘s supervisors, we agree to the submission of the thesis:

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Prof. John Derera (Supervisor)

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Prof. Pangirayi Tongoona (Co-Supervisor)

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Dedication

In the memory of my beloved mom Mrs. S.D Qwabe who regretfully did not live to see this work which resulted from her gift of love to me for many years. I thank you and I love you.

1. Introduction to Thesis

1.1 Green Maize Production and Research

Green maize (*Zea mays* L.) can be defined as the maize which is harvested before physiological maturity when it is still green. It can be boiled or roasted on the ear, or as individual grains which are processed in different recipes. Unfortunately, research on green maize production is scarcely reported in the literature. Internationally the use of green maize is a very important part of food consumption in maize producing areas (Serna-Saldivar et al., 2000). However, the scarce information about cultivars available in the market discourages the diversification of the genetic materials (germplasm) which is used for green maize production (Moraes et al., 2010). Green maize is produced for household food security and as snacks throughout sub-Saharan Africa. It is also consumed on a large scale in other developing regions and contributes immensely to food security and cash income for the households. Serna-Saldivar et al. (2000) reported that in nearly all countries except the United States of America (USA), field maize is preferred for use as green maize. Spanner et al. (1996) reported that in Trinidad maize is primarily harvested as green ears for human consumption. Mulatu and Zelleke (2002) reported that in the food deficit period, the family is fed with roasted green maize or boiled green maize and a haricot bean mixture. Moreover, green maize is sold at local markets in many countries and gives women the opportunity to earn some cash income which they can use to purchase household items and to pay school fees for the children. Kim et al. (2008) reported that green maize is usually the first farm produce to reach the market after the preceding dry season, and it therefore serves to break the hunger gap. Abalo et al. (2006) reported that in Uganda green maize is normally consumed when maize is approaching physiological maturity when most of the conversion of the sucrose to starch has taken place.

In South Africa, green maize is an important cash crop for both large and small-scale farmers. Fanadzo et al. (2010) indicated that green maize is the most important crop in the small-holder irrigation schemes (SIS) in South Africa. Green maize is produced in winter at Mjindi (MJD) and Ndumo (NDO) Irrigation Schemes in the KwaZulu-Natal

(KZN) province. Summer production of green maize has been reported at Tugela Ferry Irrigation Scheme at Msinga in the KZN. Large-scale commercial production of green maize in KZN has been reported at Camperdown and Vryheid. For household consumption immature grain maize is used in almost the whole maize producing areas in KZN. Therefore there is good reason to devote resources for the research and development of special green maize hybrids that meet the requirements for both growers and eventual consumers.

Despite the fact that green maize is produced worldwide there is limited research on the end-user, and growers' preferred traits in green maize hybrids. There is also no literature of the genetics, in particular on the combining ability of maize germplasm for use in developing new special hybrids with the preferred green maize traits. Such information is crucial for setting up a breeding programme that aims to develop appropriate and specialty hybrids for the green maize market in KwaZulu-Natal. As a result of the limited information and research on green maize, there are only a few hybrids that are suitable for green maize production and acceptable to the consumers in South Africa, especially in KwaZulu-Natal. Fanadzo et al. (2010) reported green maize hybrids used by farmers at Zanyokwe Irrigation Scheme in the Eastern Cape Province. The list of hybrids included: SR52, SC701, HL19, HL23, PAN93, PAN6549, PAN8M-95, SNK2665, SNK2147, ETZ200, ETD634, ETD646 and ETC791. In KwaZulu-Natal, the hybrids that are grown by farmers in MJD and NDO for green maize are SR52 and SC701. However, all other hybrids that are being grown in both Eastern Cape and KZN were not bred for green maize but for commercial grain production. Therefore, these hybrids do not necessarily meet most of the quality attributes that are desired by growers and the end–users of the green maize, especially in the MJD and NDO areas in KZN. A pilot informal discussion of researchers (comprising maize breeders, agronomists and horticulturists) with farmers, consumers and green-maize merchants in the area, during August 2008 indicated that currently there are no appropriate hybrid products with specialty traits that meet the stake-holders requirements and confirmed that there is a need to develop specialty hybrids for this market niche. Breeding of the farmers' required variety entails emphasizing the attributes that are perceived to give the best value to the growers, and end-users of the green maize.

Breeding strategies which focus on a particular set of traits for a model variety have been reported in the literature for dry grain maize cultivars but these strategies do not apply for green maize. Lawn and Imrie (1991) reported that various morphological and physiological traits can be combined through breeding into one plant type. Additional estimates of genetic effects, genetic correlations, heritability estimates, and combining ability data for these traits are needed to devise a viable breeding programme. This involves construction of breeding populations containing the various plant traits and selection of desired plant types within these populations. To ensure maximum marketability and other green maize traits such as high ear yielding ability are obtained in green maize hybrid varieties, parental materials (inbred lines) of the base population must possess the desired traits. Consequently, elite germplasm that has been previously selected for the desired green maize traits such as long ears, high single ear yield, and marketing ability (a product of ear length and weight) must be used in designing the breeding populations. Attention is also paid to improving the key agronomic traits to ensure that it has value for cultivation, and enhancement of dry grain yield because the product can end up as a dual-purpose product for household food and the fresh market. When farmers fail to sell the product as fresh ears it enters into the food and livestock market. This is important because there is a very narrow window for selling the green product due to its high perishability. Therefore the special hybrids must also be evaluated for grain production requirements, such as grain yield and other agronomic traits.

1.2 Objectives of the Study

The overall objective of the research was to conduct breeding investigations for the development of specialty green maize hybrids. The information would be crucial for the development of suitable green maize hybrids with desirable market and field agronomic attributes that meet the requirements for consumers and producers of the product, respectively, in KwaZulu-Natal, South Africa.

1.3 Specific Objectives

The specific objectives of the study were as follows:

1) To determine the ideal quality traits required by consumers (end-user traits) for green maize hybrids;
2) To determine farmers' requirements for green maize hybrids;
3) To determine production constraints, production trends and the economics of green maize production at Mjindi and Ndumo Irrigation Schemes in KwaZulu-Natal, South Africa;
4) To determine the combining ability of advanced inbred lines for desired green maize traits, and to identify experimental combinations with green maize production potential;
5) To investigate the relationships between green maize and selected agronomic traits.

1.4 Hypotheses tested

The following hypotheses were tested in the study:

1) Farmers and end users require special hybrid varieties for green maize production;
2) Farmers have special preferences for green maize hybrids;
3) Green maize production in the Ndumo and Mjindi Irrigation Schemes is a viable business enterprise;
4) The important traits for green maize hybrids are influenced by additive gene action;
5) There are significant positive relationships between green and agronomic maize traits that can be exploited in breeding specialty hybrids.

1.5 Outline of the Thesis

The thesis is organized in chapters as follows:

1- Introduction to thesis

2- Literature Review

3- Survey of the Green Maize production in KZN

4- Genetic analysis –Line x tester mating

5- Overview and directions for future research

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2 Literature Review

2.1 Introduction

This chapter reviews theory for the research context, and discusses importance of maize, uses of green and dry maize, types of maize, end-user and farmer’s preferences, maize production constraints, combining ability, inheritance and relationships amongst maize traits. The literature on green maize has been scarcely reported therefore most of the work reviewed in the thesis pertains to similar traits which were measured in dry grain yield trials.

2.2 Global Importance of Maize

Maize is a major cereal crop worldwide (Abalo et al. 2006; Acquaah, 2007). It is the third most important cereal in the world after wheat and rice (Abalo et al., 2006; Hefney, 2010). Radosavljevic et al. (2010) reported that the total maize production in the world in 2007 amounted to 766 million tons of grain. This is more than two-fold the amount that was previously predicted for the year 2020. Pingali and Pandey (2000) had projected production to rise to 280 million tons in 2020. This growth is due to increase in animal and poultry production (Pingali and Pandey, 2000). Radosavljevic et al. (2010) reported the global maize production in 2007 in comparison to production in 1900 and showed that it increased by 7.6 times. Kim et al. (2008) indicated that maize is the most important cereal crop in Sub-Sahara Africa, yet the production is not adequate to meet the ever rising consumption. Hefney (2010) reported that maize is produced for human, animal and industrial purposes. In South Africa production and consumption of maize is high and estimated at 12 million t/ha (FAOSTAT 2009) reflecting its role as the primary food staple for the majority of the population. Maize is the staple crop for majority of households in Southern Africa (Derera et al., 2006; Sibiya et al., 2009). In developing countries from Latin America, Africa and Southern East Asia, maize is consumed directly and serves as a staple diet for 200 million people. In Southern Africa, production and consumption of maize is high reflecting its role as a primary food staple for the majority of rural households (Magorokosho, 2006).

Maize contributes 15-50% of energy in human diets in Sub-Sahara Africa (Kagoda et al., 2009). In 2005, maize production in Sub-Sahara Africa (SSA) was estimated at 50.7 million tons of grain from 26.9 million hectares (FAO, 2007 as cited by Kim et al., 2008) indicating the average yield of about 1.88 t/ha. This level of yield is less than the global average for developing countries and the developed countries. In the recent times, average global yield per hectare has approached the level of five tons of grain, while the most developed agriculture systems have reached the levels of 7-8 tons per hectare (Radosavljevic et al., 2010). In Southern Africa small-scale and subsistence farmers dominate in maize production (Mariote et al., 2007). It is produced under diverse environmental conditions in South Africa (Du Plessis, 2003). Approximately 3.1 million tons of maize grains are produced in South Africa annually on approximately 3.1 million ha of land (Du Plessis, 2003). This indicates an average yield of about 1 t/ha thus underscoring the need to invest resources to improve productivity of this crop to meet demand in SSA.

2.3 Uses of green and dry Maize

Maize has been put to a wider range of uses than any other cereal crop. It is used as human food, as a feed grain, a fodder crop, and for hundreds of industrial purposes because of its broad global distribution, its low price relative to other cereals, its diverse grain types, and its wide range of biological and industrial properties (Dowswell et al., 1996). Maize is used primarily as human food in most parts of the world, while in the United States about 85% of the crop is used as livestock feed (Shashidhara, 2008).

In developing countries, maize is mainly used for human consumption. In Africa, dry maize is milled to flour or semolinas, which are used to make couscous (Senegal, Mali, Togo), porridges or paste (*akoume* in Togo, *akessa* in Ivory Coast and *Benin* and *agidi* in Nigeria (Mestress et al., 1990). The maize meal has other form of uses such as Ugali in East Africa, *Nsima* in Zambia and Malawi, *Sadza* in Zimbabwe and *Phuthu* in South Africa. More than half of all maize is utilized directly as human food in the Andean countries of South America, Mexico, Central America, and the Caribbean, Africa, and Southeast Asia (Dowswell et al., 1996). Maize accounts for at least 15% of total daily calories in the diets of people in 23 developing countries, nearly all in Africa and Latin

America (Dowswell et al., 1996). The cereal typically provides about 50% of the dietary protein for humans and can comprise up to 70% of the protein intake for people in developing countries. The demand for cereal grains will continue to increase as a consequence of expanding human population which could add >1.5 billion people by year 2025 (Gibbon and Larkins, 2005).

It has been reported that 16 countries with the highest maize grain consumption in the world are in Sub-Saharan Africa (Banziger and Diallo, 2002) with the largest consumption in southern Africa. Statistics have shown that the per capita consumption within Southern Africa is above that of SSA as a whole. For example, Banziger and Diallo (2002) reported that maize contributed 50% of calories in South Africa, whereas it accounts for 30% in East Africa and 15% in the West and Central Africa combined. The highest consumption of maize is found in the southern most country cluster comprising Lesotho, Malawi, Swaziland, South Africa, Zambia and Zimbabwe. Clearly maize plays the most crucial role in feeding people in these southern African countries and sustaining livelihoods. It can be deduced that low production of the maize crop has some serious implications for the human population in southern Africa. Unfortunately, most of the data is for dry grain and very little for green maize production and consumption, because the literature on the later is scarce. Therefore the current study fills an important gap in the literature.

2.4 Types of Maize

Due to the huge diversity of morphological, physiological and biochemical traits maize has been developed into different types with different uses. It is generally grown as an energy crop (with high levels of starch), but there are special types with high-lysine (quality protein maize), high-oil, white and yellow grain, sweet and popping maize. Different selection and breeding processes are followed in developing different types of maize. The processes include determination of the specialty traits such as the popping expansion, and flake qualities in popping maize, sugar content in sweet maize and oil content for programmes that aim to emphasize high-oil content in maize (Pajic, 2007) and protein profiles for the quality protein maize (QPM). However, the literature on traits and selection criteria of maize for green maize consumption is not available.

2.5 Flint and Dent Types and sugar levels in Maize

The whole outer portion of the flint kernel is composed of hard starch which does not easily form a paste with water, and its composition gives the kernel a shiny surface. In general it is perceived that flint grain is resistant to fungal and insect damage, and that the flint maize varieties tend to mature earlier and have superior germination capacity under cold soil conditions (Dowswell et al., 1996). Depending on consumer requirements, such as cooking quality and roasting both flint and dent maize types may be required in green maize varieties. The dent kernels are distinguished from the flint by having a dented crown when dry. The dent crown is formed when the softer starch in the middle of the kernel shrinks faster than the outer more translucent sides (Du Plessis, 2003). Thus, according to Dowswell et al. (1996) amylose or soft starch, this forms the core and cap, contracts when grain is dried resulting in formation of the dent crown. The hard starch is confined to the sides of the kernel (Dowswell et al., 1996).

The sweet maize is used as human food at the milk dough stage. The sweetness trait is controlled by one or several recessive alleles that change the endosperm carbohydrate composition. These include the sugary (*su*) allele at the chromosome 4. The other genes that control the sweetness traits are the *sh2*, *fl1*, *fl2*, *ae*, *se* genes in sweet maize varieties (Laughnan 1953, as cited by *Pajic*, 2007). Sugar content may be increased by presence of the mutant gene, *shrunken-2 (sh2)* (Sleper and Poehlman, 2006). Sweet maize is harvested 20-24 days after pollination and mutants with *bt*, *bt2*, *sh, sh2* and *sh4* genes contain two to three times more sucrose than the mutants with the *su* endosperm, and 4-8 times more total sugars than normal maize grain (Holder *et al.,* 1974 as cited by Pajic, 2007). The disadvantage of sweet maize hybrids with high sugar content is that germination is poorer than in *sugary* (*su*) hybrids and the seed production is more difficult (Tracy, 2001 as cited by Pajic, 2007). Hybrids with the *sh2* gene are acceptable by consumers because of their softness and consistency at the milk dough stage (Tracy, 2001 as cited by Pajic, 2007). Sweet corn is grown primarily as food and is harvested with about 70% moisture, and it can be distinguished from the green maize. For example, sugar content accounts for 20% of dry matter in sweet maize while it accounts for only 3% in dent maize at the green ear stage (Pajic, 2007). There is a need to breed for and improve the levels of sugar content to enhance sweetness in green maize varieties to improve the taste.

2.6 Green Maize Variety Design: Open-pollinated vs. Hybrid varieties

The distinct open pollinated varieties (OPVs) have been developed through repeated selection for the preferred traits by farmers, and are still grown in Africa, Latin America, and Asia. Consequently, they exhibit stability and adaptation to local communities through tolerance to prevailing diseases, pests and abiotic stresses such as drought and low fertility conditions. Because the OPVs are relatively cheap to produce and farmers can produce their own seed for at least three years on-farm the breeders have paid little attention to improving these varieties. They are required to meet local production and consumption and agronomic traits such as high standing ability, high yield, desired maturity and plant height, resistance to prevailing stresses (Pandey, 1998). For breeding purposes selection of the germplasm is crucial to design varieties with farmers preferred traits. The set of parents for use in developing new populations such as OPVs must show good combining ability for the traits that are desired in the OPVs.

Another variety option for consideration in green maize development is the hybrids. The number and genetic composition of parents for use in developing the hybrids can differ as follows (Pandey, 1998) with consequences for genetic uniformity, and agronomic performance, and seed production costs:

a) Single-cross hybrids which are produced by crossing two inbred lines;
b) Three-way-cross hybrids produced by crossing an inbred line with a single- cross hybrid;
c) Double-cross hybrids produced by crossing two single-cross hybrids;
d) Top-cross hybrids produced by crossing an inbred line and an OPV;
e) Double top-cross hybrids produced by crossing a single-cross and an OPV;
f) Varietal cross hybrids produced by crossing two OPVs.

The genetic uniformity of the product declines from the single cross (a) to the variety cross (f) in the list above, with profound implications on agronomic performance of the variety. Unfortunately, it has been shown that performance of the product is positively correlated with the level of genetic uniformity (Pandey, 1998) such that commercial farmers in developed regions in the USA and South Africa prefer the single- cross hybrids. Due to the high levels of inbreeding in the seed parent of the single-cross hybrid (inbred lines), yield is very low and often it can be less than 500 kg per ha, while that of the variety crosses which have vigorous parents can yield even more than 5 t/ha (Pandey 1998). The ultimate seed price that is passed to the farmer is to a large extent a reflection of the ease of producing the product. However the variety cross is not uniform. Thus the single cross hybrid seed is the most expensive while the variety crosses offer better seed price which can be accepted by small-scale commercial and subsistence farmers in Africa. The implications for green maize production are that the single cross variety is the best option due to superior uniformity and high ear yield of the hybrid.

Although the single cross seed is too expensive to ordinary farmers, the green maize producers can afford to buy fresh maize seeds every season since the uniformity in single cross allows them to sell their ears at premium price which can give them more return. As a result all farmers in the green maize production venture in the area under study can afford improved seed since it is a viable investment which is supported by data from the survey conducted (see the next Chapter). The choice of whether to develop hybrids or OPVs is also determined by other factors. Derera et al. (2006) indicated that farmers prefer hybrids for grain production due to their superior tolerance to abiotic stress in Zimbabwe. In Kenya, farmers also preferred a local landrace (Odendo et al., 2001) because of its superior taste and flint grain. Mulatu and Zelleke (2002) reported that small farmers preferred OPV than hybrids because they could retain seed for future use. Ultimately price is the most determinant factor regarding the product that farmers are likely to grow in developing countries.

2.7 Green and dry Maize Production Constraints

Broadly the maize production constraints are due to biotic and abiotic factors (Pingali and Pandey 2000). Derera et al. (2006) reported that maize production constraints differ between regions in Zimbabwe. The constraints that impact on maize production are the low and high temperature, rainfall regimes, and seasonal length, low soil fertility, soil acidity, soil erosion, weeds, insects and diseases (Pingali and Pandey 2000) in most developing countries.

Abalo et al. (2006) indicated that both socio-economic and biophysical factors are the main contributors to the persistent low yield in Uganda. Derera et al. (2006) reported that maize weevil (*Sitophilus zeamais* Motsch) is the most destructive pest of stored maize in southern Africa. However this literature pertains to the dry grain production. Because the residual maize from green maize varieties will be harvested dry and stored on-farm post harvest resistance to pests would be an important attribute of the green maize variety as well. Mulatu and Zelleke (2002) listed the following maize constraints in Ethiopia: maize stalk borers, leaf diseases, storage weevils, drought, poor soil fertility and lack of cultivar choice. Sibiya et al. (2009) reported that drought was ranked as the first maize production constraint at Obonjaneni and Bangisitha districts in KwaZulu-Natal in South Africa, which was followed by heavy rains, storms, low soil fertility, weeds, insects and diseases. Leley et al. (2007) also reported drought, lack of technical knowledge of crop management, poor soils, lack of sufficient seeds at planting time and high price of inputs such as fertilizer, and low market prices for grain, and disease in Kenya.

The maize diseases which are endemic to most countries in SSA are: maize streak virus, grey leaf sport (GLS caused by *Cercospora zeae-maydis* Tehon & Daniel), rust (*Puccinia sorghi* Schwein and P. *polysora* Underw.), northern maize leaf blight (NLB) caused by *Exserohilum turcicum* Pass. Leaornard & Snuggs), ear rots (*Fusarium and Diplodia*), head smuts (*Sphacelotheca reliana L*) and Phaeosphaeria leaf sport (Pingali and Pandey, 2000). Abalo et al. (2006) reported that unreliable rainfall and insects pests were the dominant constraints to maize production in Uganda. Maize streak virus disease was the most important maize production constraints in Uganda (Abalo et al., 2006). Sibiya et al. (2009) indicated that these diseases are often difficult to control since their occurrence year after year is less predictable because of their high dependence on weather. As a result, in favorable seasons with high rainfall, diseases also become more prevalent and damaging. Consequently yield is compromised with implication on food security and returns on investment. Although there is no literature on how these factors impact green maize production, they are likely to compromise quality of the ears, such as reduced ear length and kernel size and weight.

The majority of small scale farmers cannot afford in most cases, to control the diseases due to limited access to pesticides, and limited financial investments. Therefore stress tolerant varieties are desired for deployment in the smallholder farming sector. The diseases have impact on quality of green maize and grain which affect the ability to market the ears and human health. The ear rot diseases, for example, have some detrimental effects on quality of both green maize and grain ears. The ear rot infections on maize ears are associated with mycotoxins production which has been demonstrated to cause cancer (Mukanga et al., 2010). The other diseases have indirect effects on both quality and yield of ears in green maize varieties. Leaf diseases may compromise marketable yield by reducing ear size, ear weight and grain filing when the leaf area duration is reduced by disease infection. Stalk borers produce tunnels on the ears which affect the appeal of the green maize ears and also damage the maize stalks leading to poor standing ability of the varieties.

2.8 End-User Requirements for Green and Dry Grain Maize

Certain varieties of green maize are preferred by consumers and therefore breeders must identify the preferred traits that can be included in the selection index for hybrids. The grain texture of the maize is important, with floury, soft endosperm or hard endosperm maize being preferred (Serna-Saldivar, 2000). The International Institute of Tropical Agriculture (IITA 2009) reported that consumers preferred varieties with high sugar content and tender kernels. However, more information is required to determine the essential parameters affecting green maize quality (Serna-Saldivar, 2000) which can be included in the selection criteria. Maize for fresh consumption should have a higher number of usable ears per hectare. Spaner et al. (1996) found that consumers of green maize in Trinidad preferred yellow maize with large ears. The other features for green maize hybrids are tight husk cover which is long enough to protect the ear tip; many grain rows on the ear with a minimum of 16; while the kernel colour requirements vary according to the growing regions. Fresh market maize may be harvested mechanically or by hand; hence for hybrid to be widely accepted the ears should be easy to remove from the plant, and the ear placement must be uniform Spaner et al. (1996).

In some situations the early maturing varieties would be preferred. However, the extremely early hybrids have been reported to have fewer kernel rows, lower yield, or poor eating quality (Serna-Saldivar, 2000). Maize varieties can be bred for specific processing and cooking traits, and extended shelf life to meet consumer requirements (Acquaah, 2007). High yield is the most important criterion used for varietal selection in Zimbabwe (Derera et al., 2006) and in Uganda (Abalo et al., 2007). However, Kagoda et al. (2009) also indicated that biotic stress tolerance, palatability and grain storability were some of the traits that were ranked highly in Uganda. Additionally preference for large kernels which are associated with increased seed weight and higher market prices are also important in Uganda (Kagoda et al., 2009). Spaner et al. (1996) found that farmers preferred varieties which are fast maturing and with medium plant height. Odendo et al. (2001) reported that early maturing varieties were preferred because of many reasons such as: 1) early maturing varieties allows production of two crops per year to fit in the bimodal rainfall pattern; 2) early maturing also allows the crop to escape late season drought; and 3) ensures early provision of food to the households to alleviate hunger. Mulatu and Zelleke (2002) indicated gender preference for green maize, where women preferred green maize over grain maize because it provides food and cash security to the household.

2.9 Gene Action

Genes are the basic units of inheritance which are located on chromosomes and control expression of characters, either individually or in combinations. The genes determine expression of characters and therefore gene action is defined as the way genes express themselves (Welsh, 1981 as cited by Derera, 2006). In other words the gene action refers to the functioning of a gene/s in determining the phenotype of an individual, and it can be broadly divided into two categories, namely additive and non-additive gene action (Falconer, 1981 as cited by Derera 2006). The non-additive gene expression may exhibit dominance, recessivity, no dominance, over-dominance and epistasis (Acquaah, 2007; Sleper and Poehlman, 2006).

2.9.1 Additive Gene Action

Additive effects refer to the action of genes affecting a genetic trait in a manner that each gene enhances expression of the trait (Sleper and Poehlman, 2006). The phenotypic effect of one gene adds to the phenotypic effect of another gene and each of the two genes contributes to the production of quantitative phenotypes (Kananji et al., 2007). In the F_2 generation, the heterozygous genotype produces a phenotype that is intermediate between those produced by the homozygous genotypes. The heterozygotes in F_2 or advanced segregating generations are expected to be intermediate of the two parents and can be identified easily. Additive variation is associated with average effects of alleles; hence the phenotype of an individual is a good indicator of its potential genetic contribution to the progeny (Smith et al., 1989). Consequently, traits that are influenced by additive gene action are moderately to highly heritable (Kearsey and Pooni 1996). Selection is therefore possible for traits that are under the control of additive genes. The additive effects can be fixed by developing inbred line parents for use in hybrid breeding programmes.

2.9.2 Non – Additive

Non-additive gene action is envisaged when variation cannot be explained on the additive model and occurs due to interaction of alleles (Falconer, 1981). Interaction of alleles at the same locus implies dominance gene action, while interaction of alleles at different loci implies epistatic or non-allelic gene interaction effects (Derera, 1999). The non-additive gene action impacts on breeding progress because the non-additive variation cannot be fixed in a breeding population.

2.9.2.1 Dominance Gene Action

Dominance gene effects are the deviations from additivity that make the heterozygote progeny resemble one parent more than the other. When dominance is complete, the heterozygote is equal to the homozygote in effects (Acquaah, 2007). The breeding implication is that the breeder cannot distinguish between the heterozygous and homozygous phenotypes in classical breeding programme. Consequently, both kinds of plants are selected, homozygotes breed true, while the heterozygote does not breed true in the next generation (Acquaah, 2007). Unayi et al. (2004) reported that grain yield of maize is under the dominance gene action. On the basis of the hereditary scale, over dominance gene action occurs when the heterozygous genotype effect is outside the effects of either parent. Partial dominance occurs when the heterozygote has a value that is closer to one parent than the other (Welsh, 1981). It can be either positive or negative. Positive partial dominance is when the performance of the heterozygote lies between *m* (the mid parent value) and the value of the superior parent, whereas negative partial dominance occurs when performance of a heterozygote lies between the midpoint value *m* and the value of the inferior parent on the hereditary scale. Positive complete dominance occurs when the performance of the heterozygote equals that of the superior parent; while negative complete dominance occurs when performance of the heterozygote equals that of the inferior parent (Derera, 1999). The dominance gene effects cannot be fixed during breeding but they can be exploited in a hybrid oriented programme that aims to release the F1 generation as the product. Significance of the dominance gene effects gives an indication that maize varieties can be developed through hybridization of parents.

2.9.2.2 Epistasis Gene Action

Epistasis is the interaction between genes at two or more loci. In epistatic interaction one gene may control the degree to which another gene is expressed. Iqbal et al. (2009) found that epistasis plays a considerable role in controlling plant height. Generally large epistatic effects reduce heritability because they cannot be fixed to facilitate selection of parents with potential for green maize production. However, a positive epistasis of additive x dominance and dominance x dominance type can be exploited in developing hybrids; while the additive x additive epistatic effects can be fixed in developing inbred parents during pedigree selection.

2.9.3 Combining Ability

Combining ability (CA) can be defined as a measure of breeding value of parent lines to produce crosses in hybrids oriented breeding programmes. In other words combining ability is the ability of inbred lines to produce the desired progeny in hybrid combination. The CA is partitioned into general combining ability (GCA) and specific combining ability (SCA) which is defined by Sprague and Tatum (1942). General combing ability is the average performance of inbred lines in hybrid combination. According to Sprague and Tatum (1942), the cases in which certain hybrid combinations do better or worse than the average performance of the inbred lines involved is called the specific combining ability.

Malik et al. (2004) reported that the mathematical modeling of GCA and SCA was set about by Griffing (1956). Karari et al. (2006) reported that the concept of combing ability is predominantly applied to open pollinated crops such as maize. Kanagarasu et al.

(2010) indicated that combining ability is important in designing plant breeding programmes. Sprague and Tatum (1942) and Malik et al. (2004) reported that the variance of specific combining ability includes the residue as well as dominance, epistatic and interaction effects. Garvina et al. (2003) as cited by Munga et al. (2008) indicated that when GCA effects are significant, selections can be made on segregating and advanced generations to produce pure lines with additive gene effects. Kanagarasu et al. (2010) indicated that GCA and SCA can be used as a statistical tool to measure the extent of additive gene, and non-additive gene actions in heterosis breeding.

Yingzhong (1999) reported that the combining ability analysis is an important method to know gene action and it is frequently used by crop breeders to choose the parents with a high general combining ability and hybrids with high specific combining ability effects. Novoselovic et al. (2004) as cited by Zare et al. (2010) indicated that beside gene effects, breeders would also like to know how much of the variation is heritable, since efficiency of selection mainly depends on additive genetic variance. Mohanty and Khush (1985) explained that if the variance due to SCA is greater than the variance due to GCA that indicates predominance of dominance or epistasis. In this case large SCA would be exploited to make hybrids while large GCA variance indicates that selection of parents with large GCA is effective in developing green maize varieties.

2.9.4 Determination of Combining Ability – Diallel Approach

Diallel mating is the most commonly used method to study the genetic properties of inbred lines (Sharma and Fanta, 2010). A diallel cross is the set of all possible mating between several genotypes. According to Johnson and King (1997), the diallel mating design distinguishes between the GCA of parents in crosses and the SCA effects. Mtunda et al. (2009) indicated that the mating design permits an estimation of the magnitude of additive and non-additive components of heritable variance. The diallel cross method has been utilized widely in maize breeding programmes to evaluate the genetic potential of inbred lines and other genotypes, but its limitation is the increasing number of crosses in accordance with the increase in number of lines (Kempthorne and Curnow, 1961; Meirelles et. al., 2009). Therefore, as the case in the current study, when the number of lines is large (> 10) other factorial mating designs can be suggested.

2.9.5 Determination of Combining Ability – Line X Tester Analysis

The line x tester technique can be used for screening genotypes for GCA and SCA effects. The number of crosses generated is the product of lines and testers. According to Singh (2003) several types of testers have been suggested but there are issues to consider when selecting testers:

1) Heterozygous testers are superior to the homozygous ones;

2) The best inbred line has a masking effect due to its desirable dominant alleles; therefore, it should not be used as a tester;

3) An inferior synthetic developed by crossing together poor lines may be used as tester.

In general a tester should be poor in the traits for which the lines are to be analyzed, and should be highly adaptable to the environment. The choice is essentially to find a tester that provides the best discrimination among genotypes according to the purpose for selection (Hallauer and Miranda, 1988). A desirable tester combines the greatest simplicity in use while providing maximum information on performance of the lines used in other combinations or grown in other environments, and correctly identifies superior lines and maximizes genetic gain (Matzinger, 1953; Hallauer and Martinson 1975). Testers are used for the determination of heterotic relationships among genotypes. In the current study, line x tester mating was adopted because the objective was to identify experimental lines with potential for use in green maize production. Also the line x tester scheme was chosen instead of the diallel because there were far too many lines (100) for combining in a diallel mating.

2.10 Combining Ability for Green Maize and Other Desirable Traits

The combining ability of maize for green maize traits has been scarcely reported in the literature. Therefore most of the literature has been reported for dry grain yield (Kim et al., 2008; Cropper et al., 1974 as cited by Spaner et al., 1996). Wali et al. (2010) reported significant GCA effects for maize yield. Spaner et al. (1996) reported the significant SCA effects for grain yield and that non-additive effects were superior to additive effects.

Several researchers have reported that GCA and SCA effects were highly significant for days from emergence to silking, days from emergence to physiological maturity, plant height and ear length and significant for ear height and grain yield (Zare et al., 2010; Singh et al., 1983 as cited by Derera et al., 2006; Sibiya et al., 2011; Irshad –Ul-Haq, 2010). These findings indicate that additive and non-additive gene effects are important in the inheritance of these traits in maize. Sibiya et al. (2011) found that both GCA and SCA effects were important for yield and anthesis dates, and that GCA accounted for 66-90%, while SCA was 10-34% of the variation, indicating that GCA effects were preponderant. Zare et al. (2010) found that both SCA and GCA mean squares were significant for plant height, average ear length and weight. Kumar and Bharathi (2009) and Wali et al. (2010) reported significant SCA effects for ear length. Significance of both GCA and SCA effects of genotypes for grain yields have also been reported (Unayi et al., 2004; Wali et al., 2010; Jebaraj et al., 2010). Spaner et al. (1996) reported that both GCA and SCA effects were significant for marketable ears, while only the GCA effects were significant for ear length. Previously, Dhillion and Singh (1976) also reported that GCA was more important than SCA effects for ear length.

2.11 Heritability and Inheritance of Green and Grain Maize Traits

Heritability is the measure of the degree to which the variance in the distribution of phenotype is due to genetic causes. In the broad sense it is measured by total genetic variance divided by the total phenotypic variance (Falconer, 1981). In the narrow sense it is measured by genetic variance due to additive genes divided by total phenotypic variance (Falconer, 1981). Hallauer and Miranda (1988) reported heritability estimates of

41% for yield, 81% plant height, 84% ear height and 66% ear length in maize. Unayi et al. (2004) reported 23.6% heritability in the narrow sense and broad sense heritability of 96.15% for yield suggesting that non-additive variance was larger than the additive variance. These findings imply that yield can b improved by exploiting the non-additive variance to create hybrids.

The inheritance of green maize traits has been scarcely reported in the literature. Therefore in this chapter the literature for maize traits is based on (dry) grain maize unless otherwise stated. Velasquez et al. (2008) reported that grain yield was controlled by genes with additive and dominance effects in acid and non - acid soils. They also reported some epistatic gene effects for yield in 14 to 21% of the crosses in acid and non-acid soils, respectively. According to Velasquez et al. (2008) study in Brazil, the most important gene effects were dominance and additive and the least was epistasis for yield, plant height, mid silking days and prolificacy. Velasquez et al. (2008) found that additive effects, epistatic effects and dominance effects were all important in controlling plant height but with different crosses. Velasquez et al. (2008) cited that the number of days to mid silking was conferred by genes with additive (7-39% of crosses), dominance (75-78%) and epistasis effects (9.5-25%) indicating that dominant effects were predominant. With respect to prolificacy, Velasquez et al. (2008) reported that only additive and dominance effects were significant, but dominance gene effects were preponderant. Anner and Mosa (2004) as cited in Wannows et al. (2010) reported heritability estimates as follows: 44% silking dates, 39% plant height, 44% ear height, 27% ear length and 36% grain yield. Wannows et al. (2010) reported the following heritability estimates: 85% plant height, 83% ear height, 82% physiological maturity, 73% ear length, 34% silking dates and 39% yield. Zare et al. (2010) reported importance of non-additive gene action in the inheritance of days from emergence to silk emergence, days from emergence to physiological maturity, plant height, ear height and grain yield. Abalo et al. (2006) indicated that selection for large and high density kernel would be easy as these can be selected by visual assessment and by determining the mass of 100 kernels, respectively. Sweet taste for green maize can be selected using palatability tests.

2.12 Relationships among Traits

The correlation is a statistical measurement of the relationship between two variables, and is very useful in studying the relationships between traits in plant breeding. Possible correlations (r-values) data ranges from +1 to -1. A zero correlation coefficient indicates that there is no relationship between the two variables. A correlation of -1 indicates a perfect negative correlation, meaning that as one variable increases in one direction, the other one decrease by a similar value in the opposite direction. A correlation of +1 indicates a perfect positive correlation, meaning that both variables move in the same direction together.

Relationships between traits in green maize is scarcely reported in the literature, therefore the relationships in dry maize grain are reported in the current study. Wannows et al. (2010) reported highly significant correlation between yield and ear length, but yield was not significantly correlated with the other traits such as ear height, plant height, physiological maturity, and silking dates. Hallauer and Miranda (1988) reported genetic correlation between yield and the following traits: plant height (26%), ear height 3%, number of ears per plant (43%), ear length (38%) and days of flowering (14%). Hallauer and Miranda (1988) found that yield was positively correlated with ear height and ear length; however yield was negatively correlated to days to flowering. Spaner et al. (1996) found that phenotypic correlations between yield and secondary traits were medium ($0.35<r<0.76$) positive and significant ($P=0.01$). They also reported that genotypic correlations were directly proportional to phenotypic counterparts and that they were all strong ($0.57<r< 0.92$), positive and significant ($P =0.01$) for yield and secondary traits. Unfortunately the relationship between the marketability indexes for green maize with other desired traits has not been investigated. It would be of interest to the breeders to investigate whether marketability of green ears and the desired agronomic traits for hybrids are mutually exclusive or not. The current study sought to find out whether the desirable traits in green maize are negatively correlated with agronomic traits or not with implication on breeding strategy.

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3 Attributes of an Ideal Green Maize Hybrid and Production Constraints in KwaZulu-Natal, South Africa

3.1 Abstract

Green maize (*Zea mays* L) provides food security with potential to generate cash income for rural households in Sub-Saharan Africa. However, research on green maize production has been scarcely reported worldwide, which negatively impacts on both variety development and management. A case study was conducted at Mjindi and Ndumo irrigation schemes in KwaZulu - Natal South Africa, to determine the ideal quality traits preferred by consumers, agronomic properties of green maize hybrids, constraints, production trends and enterprise viability. A formal questionnaire was deployed to 64 green maize growers and the interviews were structured on a one-on-one format. The data was analyzed using the SPSS computer programme. Generally results indicated gender balance for land rental, livestock ownership and household assets ownership with implication on productivity. However, male farmers had more working capital than their female counterparts which influenced the returns per hectare in favour of male farmers. The study identified the principal desired traits for specialty hybrids as a combination of sweet taste, long shelf life and large ears. The complementary traits for the model hybrids were high grain yield potential, high selling ability, flint grain texture, white grain color, medium ear placement, thick and long cobs, short maturity period, medium plant height, and good roasting ability (non-popping). Furthermore enterprise budget analysis revealed that the total cost of R11000 per hectare for green maize production was needed. This study also showed the average return of R21000 per ha and gross margin of about R10000 per ha. Green maize was produced in two seasons per year which doubled farmers' income to about R35000. There is thus a great potential in green maize business. However, lack of suitable green maize hybrids especially for summer production appeared to be the major hindrance. Future studies should aim to improve both the genetics and production economics.

3.2 Introduction

Green maize is produced for household food security and as snacks throughout sub-Saharan Africa. It is consumed after roasting or boiling on the cob and is a source of energy for the households. Fanadzo et al. (2010) indicated that green maize is the most important crop in the small-holder irrigation schemes (SIS) in South Africa. Green maize is produced in winter at Mjindi (MJD) and Ndumo (NDO) Irrigation Schemes in the KwaZulu Natal (KZN) province. Fanadzo et al. (2010) reported that green maize is produced at Zanyokwe Irrigation Scheme in the Eastern Cape Province. Green-maize is widely produced in West Africa, Central, East and Southern Africa (Kim et al., 2008). Spaner et al. (1996) reported that green maize is also important for human consumption in Trinidad. Moreover; green maize is an easily sold item, either to the village or nearby town market therefore gives the women more financial freedom for the purchase of condiments, salt and kerosene. However, it appears that consumers prefer varieties which are high in sugar content, with large kernels and little chaffiness. Large ears may bring a better price than small ears in the market (IITA, 2009).

Maize is used for three main purposes: as a staple food, as feed for livestock and poultry, and as a raw material for many industrial products. In Africa nearly all maize grain is used for human food, prepared and consumed in many ways. Maize ears are eaten boiled or roasted (Mestress, 1990) and shelled and ground to make green maize bread and cooked with beans or peanuts (amaqobo). But the grain is usually ground and the meal is boiled into porridge or fermented into beer. In South Africa especially KwaZulu Natal, maize is consumed as dry porridge (*uphuthu*) and thin porridge (idokwe/ipapa) and consumed during breakfast. Maize is also consumed as thick porridge ('*ugali*' in East Africa, '*sadza*' in Zimbabwe) (Brink and Belay, 2006).

Green maize falls under specialty maize, and under the horticulture discipline; being predominantly a third world product of maize it has not been researched; there are no breeding programmes that emphasize green maize; and also that requirements for both farmers and consumers have not been identified. The International Institute of Tropical Agriculture (IITA) (2009) suggests that further assessment is needed to understand better the value of maize as a vegetable.

Despite the fact that fresh maize is important for household food security and as snacks throughout sub-Saharan Africa and in other developing regions, there is limited research on the end-user traits, and growers' preferred traits for green maize hybrids. Such information is crucial for setting up a breeding programmes that aims to develop appropriate and specialist hybrids for the green maize market in KwaZulu-Natal. As a result of the limited information and research on green maize hybrid development and the whole value chain, there are only a few hybrids that are suitable for green maize production and acceptable to the consumers in South Africa, especially in KwaZulu-Natal. The few hybrids that are considered suitable for green maize production were actually developed for dry grain production and not necessarily for the green maize market. For green maize certain varieties are preferred by consumers. The IITA (2009) reported that varieties with high sugar content and large ears are preferred.

3.3 Research Objectives

The objectives of the study were as follows:

a) To determine the ideal quality traits required by consumers (end-user traits) for green maize hybrids;
b) To determine the required agronomic traits for green maize hybrids, and
c) To determine production constraints, production trends and the economics of green maize production at Mjindi and Ndumo irrigation schemes in KwaZulu-Natal, South Africa.

3.4 Research Hypotheses

Farmers and end users require special hybrid varieties for green maize production and use which might have traits that are different from hybrids for grain production. Secondly, there are specific agronomic traits that farmers desire for green maize production. Thirdly, there is a potential in green maize business but there are also some constraints that hamper adequate production which compromise viability of the enterprise in Mjindi and Ndumo.

3.5 Materials and Methods

Study area

The study was conducted at Mjindi and Ndumo irrigation schemes near Makhathini Research Station in Northern KwaZulu-Natal in South Africa which fall under latitude 27^0S and longitude 32^0E, and the altitude is about 77 m above sea level (See Appendix 1 for the detailed descriptions). The schemes are situated in a sub-tropical climate with hot summer and mild winter with base temperature generally above 10^OC. The 4 years maximum monthly mean temperature is 30^0C however high temperatures are experienced in February with an average mean of 34^0C. The four year minimum mean temperature is 16^0 C with the minimum dropping to 8^0C in July. The four year average mean rainfall is 428 mm per annum, of which 85% falls between October and March. Thus the area is characterized by a mono-modal rainfall, hence the dry season production (April to September) has to be supported by irrigation. The weather condition of the area during 2007 to 2010 is summarized in Appendix 1.

Both schemes are characterized by diverse farming practices comprising of crop and animal production. Sugar cane and cotton are major industrial crops for Mjindi, while, Ndumo only specializes in cash crops such as green maize and other vegetables. Mjindi Irrigation Scheme was developed in 1979 with 600 ha established for commercial production. It has expanded to 3927 ha developed for small scale farmers. Ndumo is 520 ha from which only 200 ha are under irrigation. The population is on record of being one of the poorest in South Africa, and the area has been demarcated as presidential poverty node in need of development. Water for irrigation is supplied by Pongolapoort Dam for Mjindi and Ndumu/Msunduzi Dam for Ndumo. The annual water allocation for Mjindi farming is 33 million m^3.

Selection of farmers

Prior to the study a meeting with green maize producers was called in both areas. The aim of the study was discussed with farmers at the meeting. A list of green maize farmers with their contact details was compiled for both sites. Farmers were randomly called for interview in their respective fields by a trained enumerator. At least 64 farmers were interviewed.

Data collection

A formal questionnaire was deployed on 64 fresh mealie growers in Mjindi and Ndumo irrigation schemes. The interview was structured in a one-on-one format to prevent biasness of the answers from the farmers. The following information was collected: farmers' background, household resources, livestock production, crop production and green maize production. Additional information was collected through informal focus group discussion with farmers and opinion leaders. The data was analyzed using the SPSS computer programme.

3.6 Results

Farmers' background

This study showed that farmers' ages ranged from 24 to 66 years. Their farm sizes ranged from 1 to 40 ha. Farming experience ranged from 1 to 34 years (Table 3.1). The assets owned by farmers were motor vehicles, motor cycles, bicycles, television sets, radios, and tractors (Table 3.2). Farmers invested in livestock such as cattle, goats, sheep, donkeys, pigs, and chickens. Only a few can be leaders in any one community. There was a chief and religious leaders, however, the majority of the farmers were ordinary citizens and government officials.

Number of cattle owned by farmers ranged from 1 to 55, mean average was 8, the number of donkeys ranged from 0 to 2 mean average 0, sheep range from 0 to 12 mean average 0, goats range from 0-100 mean average 10, pigs ranges from 0 to 30 min average 1 and chickens ranges from 0 to 100 mean average was 16. Movable assets owned by farmers are motor vehicle (20%), motorcycle (2%), bicycle (5%), television (30%), radio (35%) and tractors (9%) (Figure 3.1 and Table 3.2).

Table 3.1: General information of the farmers (n = 64)

	Minimum	Maximum mean
Age (Years)	24	66
Number of years farming	1	34
Cattle (No.)	1	55
Donkey (No.)	0	2
Sheep (No.)	0	12
Goats (No.)	0	100
Pigs (No.)	0	30
Fowl/chickens (No.)	0	65
Farm size (hectares)	1	40

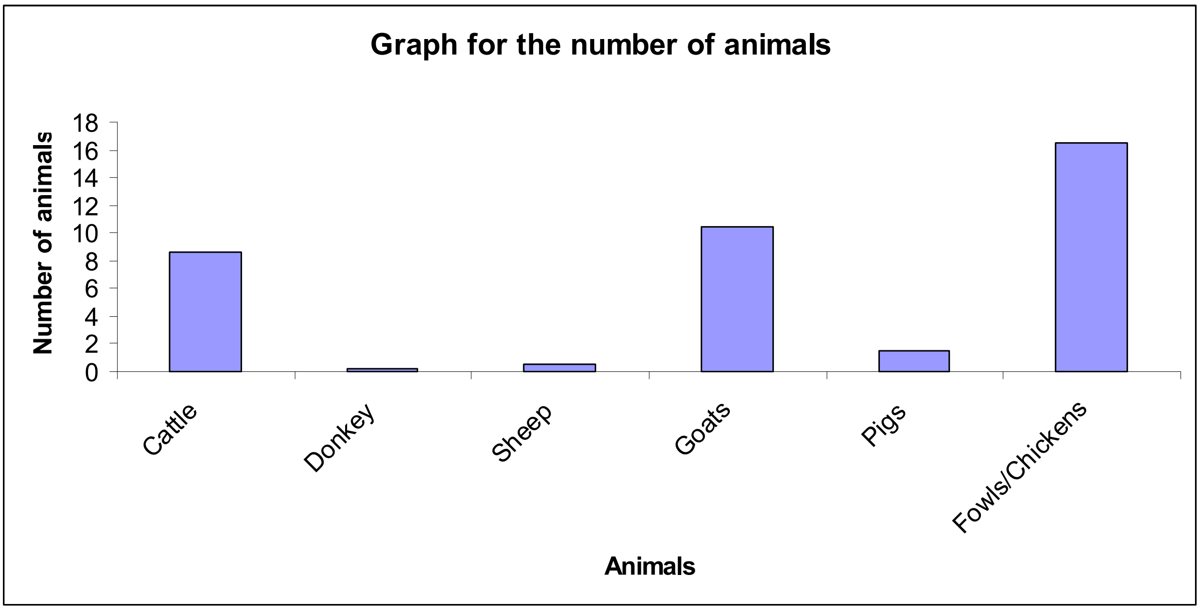

Figure 3.1: Types of livestock owned by farmers at Mjindi and Ndumo Irrigation Schemes

Table 3.2: The movable assets owned by farmers in a household

Assets	N	Percent owning the asset
Motor vehicle	34	19.7%
Motor cycle	4	2.3%
Bicycle	8	4.6%
Television	51	29.5%
Radio	61	35.3%
Tractor	15	8.7%

Gender differences

There were significant differences between gender groups for the number of green maize ears that were sold, number of cattle, goats, and farm sizes owned. However, there were no significant differences (P>0.05) between the gender groups for the area of land planted to green maize during the 2007 to 2010. There were no statistical significant differences at P= 0.05 between gender groups for the tractor ownership, motor vehicle ownership, bicycles, television sets and radios (Table 3.3). However, the data in Fig. 3.2 shows that in general males owned more assets than females.

Table 3.3: Comparison between male and female farmers for ownership of assets and green maize sales at Mjindi and Ndumo Irrigation Schemes during 2007 to 2010

Parameter	Source of Variation	d.f.	Mean Square	F	P>F
No. dozens of maize ears sold	Between Groups	1	727484.969	9.706	0.003
	Within Groups	61	74952.687		
No. of cattle	Between Groups	1	1241.655	6.976	0.010
	Within Groups	61	177.978		
No. of goats	Between Groups	1	2162.250	8.737	0.004
	Within Groups	62	247.480		
Farm size (ha)	Between Groups	1	664.960	11.054	0.001
	Within Groups	61	57.801		
	Total	62			
Area planted in 2007 (ha)	Between Groups	1	12.074	1.489	0.228
	Within Groups	50	8.108		
Area planted in 2008 (ha)	Between Groups	1	5.443	.668	0.418
	Within Groups	51	8.148		
Area planted in 2009 (ha)	Between Groups	1	9.371	1.087	0.302
	Within Groups	54	8.620		
Area planted in 2010 (ha)	Between Groups	1	4.439	.589	0.446
	Within Groups	60	7.531		
No. of tractors	Between Groups	2	80466123.670	1.571	0.216
	Within Groups	61	51234461.109		
No of motor vehicles	Between Groups	2	141757654.031	2.880	0.64
	Within Groups	61	49224902.737		
No. of bicycles	Between Groups	2	187742187.500	3.934	0.25
	Within Groups	61	47717213.115		
No. of televisions	Between Groups	1	49208733.974	.943	0.335
	Within Groups	62	52210090.984		
No. of radios	Between Groups	1	97207052.596	1.890	0.174
	Within Groups	62	51435924.555		

In general, the results indicate that male farmers had more live stocks, larger land sizes and higher sales than their female counterparts (Table 3.4).

Table 3.4: Assets and returns per hectare by gender

	Mean	
Assets	**Male**	**Female**
Cob sold	1102.72	887.7
Cattle	14	4
Donkey	1	0
Sheep	1	0
Goats	16	5
Pigs	2	1
Fowls/chickens	20	12
Farm size	11	4.95
Return/ hectare (R)	22531.25	19687.5

The slight gender differences were also observed for ownership of household assets. Figure 3.2 show that male farmers had more movable assets, such as motor vehicles, motor cycles, bicycles and tractors. Nevertheless, there were not any clear differences for the number of radios and television sets owned by male and female farmers.

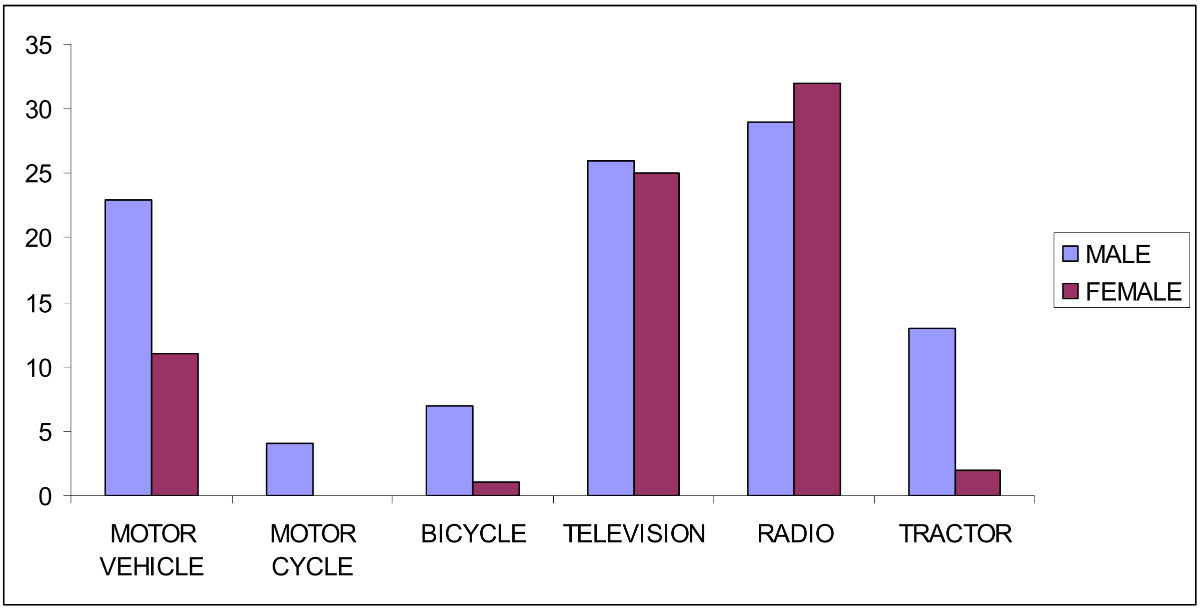

Figure 3.2: Movable assets owned by farmers in a household

The data in Figure 3.3 shows that there was no clear difference between male and females for uses of the residual maize grain after the green maize sales. The study showed that farmers sold the remaining grains and kept part of it for home consumption and livestock feed (Figure 3. 5). There was no clear difference in production trends between male and female farmers during the past four years, however, males utilised more land than females but the difference was small (Figure 3. 4).

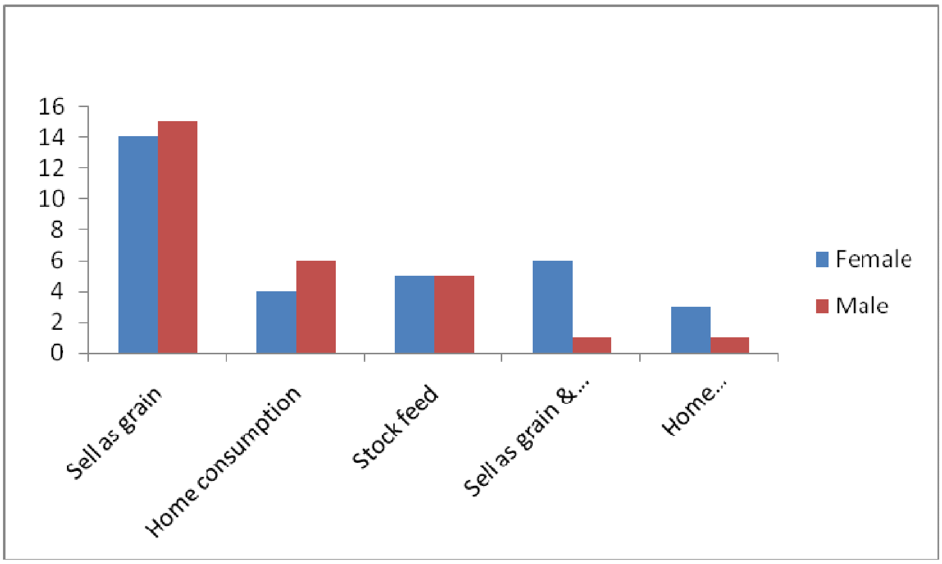

Figure 3.3: Uses of remaining maize by gender

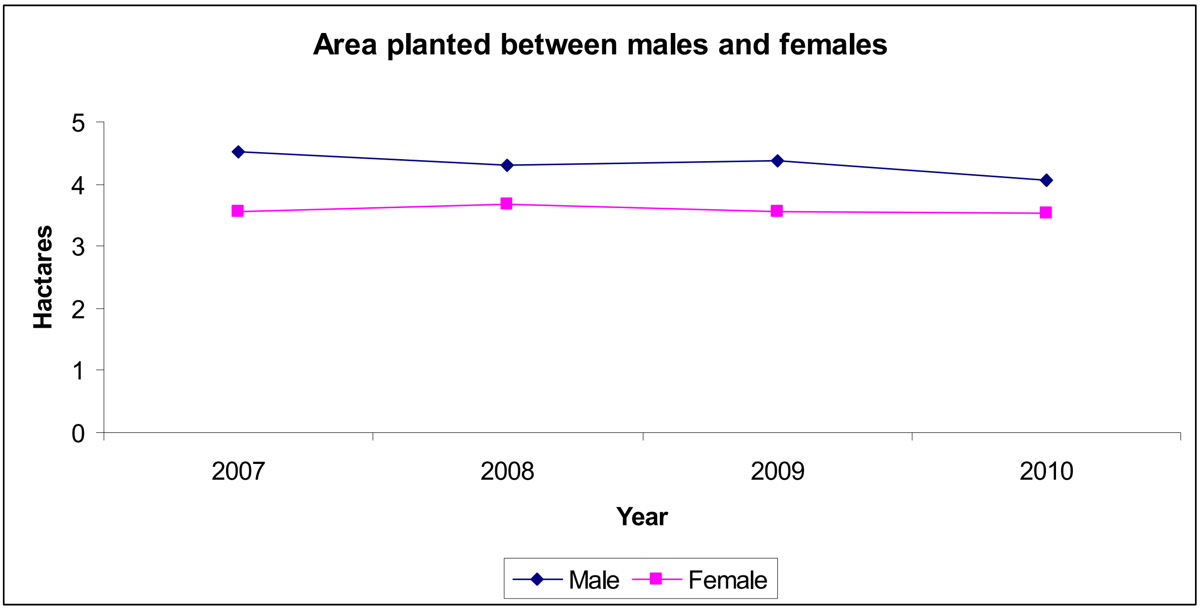

Figure 3.4: Land utilization by male and female farmers during 2007-2010

Production trend

There was a slight decrease in land planted to green maize from 2007 to 2009 (Figure 3.5). However, 2010 showed a drastic decrease in land planted to green maize compared to 2007, 2008, and 2009. The major seed suppliers were Bayer and Vencam seed companies. Some farmers bought seed from other countries such as Swaziland (Figure 3.6).

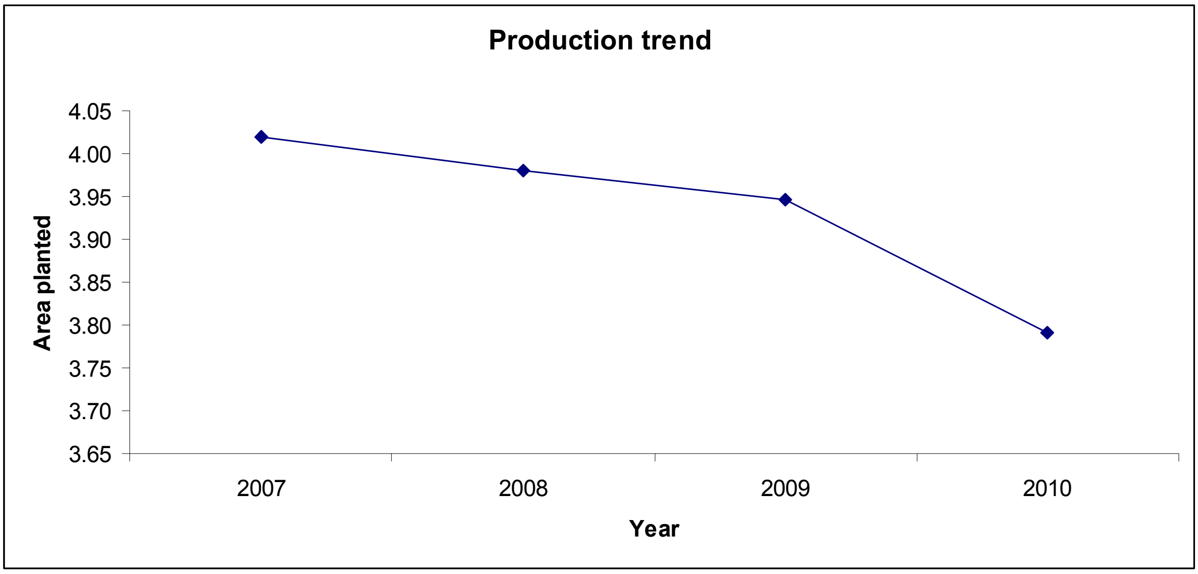

Figure 3.5: Green maize production trends at Mjindi and Ndumo irrigation Scheme in 2007 – 2010

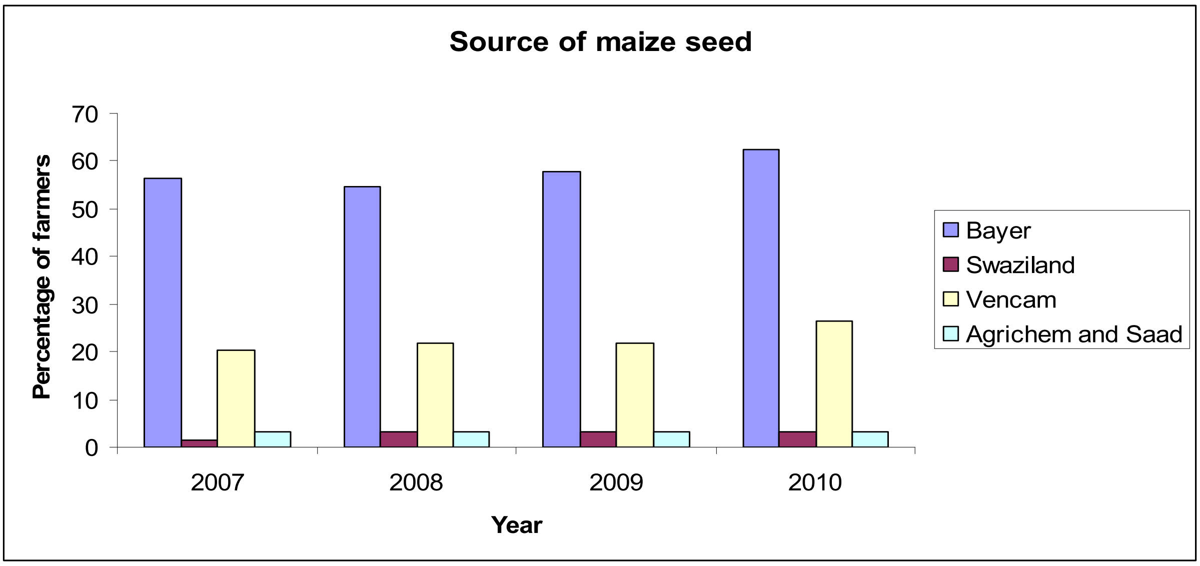

Figure 3.6: Source of seed in 2007-2010

Green maize production constraints

Factors considered by farmers when growing green maize were high yield, market preference, taste and keeping quality, and thick long cobs and sweet taste (Table 3.5). However farmers faced constraints in getting a hybrid which combines all these factors and the predominant hybrid was showing more undesirable attributes than desirable ones. The major cash crops planted in the irrigation schemes were maize, beans and potatoes. The study showed that, green maize required small quantity of seed, planted in a hectare. On average a farmer needed 20 kg of seed for green maize, 50 kg of beans and 40 kg of potato seed to plant one hectare (Figure 3.7). According to the survey green maize seed cost R1173, beans seeds R1500 and seed potatoes cost R4800 for a hectare. Seemingly, the lower cost of seed maize relative to competing crops was not a benefit to farmers because the seed quality of the predominant hybrid was attacked by diseases. One farmer reported a return of R3000 per hectare due to poor quality. Poor quality is not an isolated factor from other factors which reduces return per hectare. Factors such as crop management, market research and production plans also compromise green maize production returns. Figure 3.8 indicated that the majority of the farmers bought green maize seed in March and a few in February of each year. This shows that farmers plant their green maize at the same time. This causes a glut in the market and reduction in green maize price.

Table 3.5: Factors considered by farmers when selecting the best hybrid for green maize production during 2007 -2010

Factor	2007	2008	2009	2010
		……………. % ………………..		
High yield	25	20.3	17.2	6.3
Only green maize variety	67.2	65.6	64.1	57.8
Hybrid preferred by market	71.9	67.2	67.2	60.9
Taste and keeping quality	100	98.4	98.4	98.4
Fat, long cobs and taste		18.8	15.6	4.7

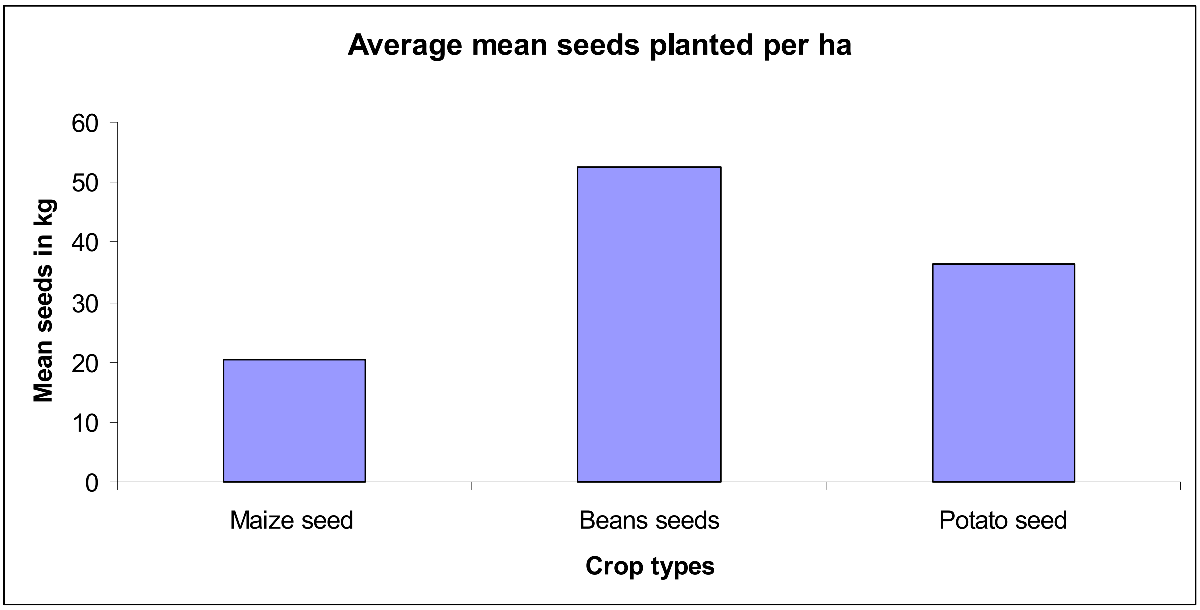

Figure 3.7: Quantities of seeds require in planting a hectare of green maize, beans and potatoes mentioned by farmers.

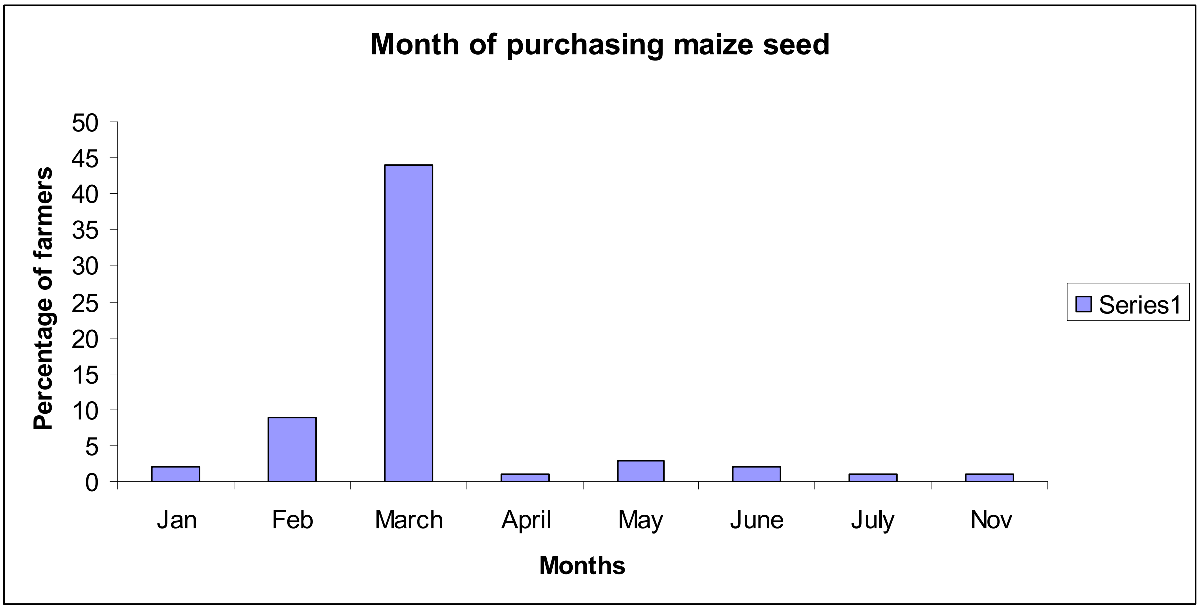

Figure 3.8: Months of purchasing green maize seeds

Relationships among production factors

Number of cattle, goats and chickens were positively correlated to the return per hectare (Table 3.6). However there was a negative correlation between the number of donkey and sheep, and no relationship between pigs and returns per hectare. Number of cattle was also positively correlated and significant for the area planted in 2008 and 2010. However, number of cattle was positively correlated to the area planted in 2007 and 2009 but not significant (Table 3.7).

The age of farmers was positively correlated and significant to farm size, number of dozens of cobs sold, and quantities of fertilizer applied (LAN) and number of years farming (Table 3.7). However age was positively correlated with fertilizer applied (MAP) but not significant. Farm size was positively correlated and significant with the age of farmers, number of green maize cobs sold, fertilizer (MAP and LAN) applied and number of years farming. Number of dozens of cobs sold was positively correlated and significant with age, farm size, fertilizer applied and number of years farming. Fertilizer applied (MAP) was positively related and significant with farm size, number of dozens sold, LAN applied and number of years farming. Quantity of fertilizer applied (LAN) showed a very strong relationship with the number of years of farming (Table 3. 7).

Table 3.6: Phenotypic correlation between number of livestock and farm size.

Number of livestock	Statistic	Farm size				Return per hectare
		2007	2008	2009	2010	
Cattle	r	0.236	0.292*	0.246	0.298*	0.352**
	Sig. P	0.096	0.036	0.070	0.020	0.005
Donkeys	r	0.155	0.257	0.258	0.264*	-0.046
	Sig. P	0.274	0.064	0.054	0.038	0.715
Sheep	r	0.218	0.118	0.127	0.187	-0.027
	Sig. P	0.121	0.400	0.352	0.145	0.835
Goats	r	0.176	0.200	0.150	0.180	0.399**
	Sig. P	0.212	0.151	0.271	0.161	0.001
Pigs	r	0.164	0.165	0.092	0.107	0.068
	Sig. P	0.246	0.238	0.501	0.414	0.596
Fowls/chickens	r	0.195	0.191	0.122	0.101	0.401**
	Sig. P	0.166	0.170	0.371	0.433	0.001

*, ** Correlation is significant at the 0.05 and 0.01 level (2-tailed), respectively.

Table 3.7: Correlation between age, farm size, no of ears sold, fertilizer applied and number of years farming (N=64)

		Age	Farm size (ha)	No dozen of Ears sold	Fertilizer applied (MAP)	Fertilizer applied (LAN)	Number of years farming
Age	r	1.000	0.419**	0.315*	0.204	0.265*	0.582**
	Sig. P		0.001	0.012	0.109	0.034	0.000
Farm size (hectares)	r	0.419**	1.000	0.347**	0.273*	0.448**	0.352**
	Sig. P	0.001	.	0.006	0.032	0.000	0.005
No dozen of cobs sold	r	0.315*	0.347**	1.000	0.274*	0.261*	0.249*
	Sig. p	0.012	0.006	.	0.031	0.039	0.049
Fertilizer applied (MAP)	r	0.204	0.273*	0.274*	1.000	0.368**	0.302*
	Sig. P	0.109	0.032	0.031	.	0.003	0.015
Fertilizer applied (LAN)	r	0.265*	0.448**	0.261*	0.368**	1.000	1.000
	Sig. P	0.034	0.000	0.039	0.003	.	.

*, ** Correlation is significant at the 0.05 and 0.01 level (2-tailed), respectively; MAP (Magnesium ammonium phosphate); LAN (Lime ammonium nitrate)

Economics of production

Enterprise budget analysis in Table 3.8 revealed that the total cost of producing one hectare of green maize was R11, 263. Expenses involved were land preparation, planting and spraying with pre-emergence herbicides, labour, irrigation, maize seeds, fertilizers, herbicides and land rental. This study showed that the average return per ha was R21,109 giving a gross margin of R9, 846 per ha in one planting season. From this study it was observed that farmers grew maize twice in a year, therefore their gross margin was estimated to increase to R19, 692 per ha per year. However, the mean average farm size was 8 ha, therefore, a total potential gross margin for 8 ha with two green maize crops is about R315, 072 (Table 3.8). This is based on the assumption that both crops yield the same.

Table 3.8: Enterprise budget estimate for green maize production per hectare in Makhathini and Ndumo Irrigation scheme in KwaZulu-Natal, South Africa

Expenses (A)		**Price(R)**
	Land preparation	2,000
	Planting & spraying	850
	Labour: weeding	850
	Side dressing	100
	Stock borer control	100
	Spraying Pesticides/ Fungicides	400
	Irrigation	800
	Seeds	1,173
	Herbicides	825
	Fertilizer	2,565
	Land rental	1,600
Total cost		**11,263**
Revenue (B)		**21,109**
Gross margin (A-B)		**9,846**

Green Maize Hybrid Model

Traits of a model hybrid required by farmers are presented in Table 3.9. The most desired traits were combination of taste, shelf life and long cobs. The major required traits for the model green maize hybrids were high grain yield potential, high selling ability, flint grain texture, white grain color, medium ear placement, fat and long cobs, short maturity period, medium plant height, long shelf life and non popping during roasting (Table 3.10).

Table 3.9: Combinations of the good attributes of the predominant market preferred green maize hybrid

Attributes	**Mean percentage**
Keeping quality, sweet taste, and long cobs	51.6
Long and fat cobs, sweet taste of meal	53.1
Market, big cob, long shelf life, sweet taste	56.3
Mature early in summer	59.4
Pest resistance, husk cover,	64.1
Preferred by buyers, keeping quality	65.6
Preferred by buyers, sweet taste, disease resistance, mature early, big cobs	67.2
Preferred by buyers, sweet taste, keeping quality	68.8
preferred by buyers, keeping quality, stay green	70.3
Required by buyers	73.4
Required by market, sweet taste, roasting quality	76.6
shelf life, cob size long and big	79.7
Shelf life, sweet taste, long cob	81.3
Shelf life, sweet taste, required by market	82.8
Sweet taste, High yield, Late drying,	84.4
Sweet taste, high yield, late drying, big cobs	85.9
Sweet taste, big cob	87.5
Sweet taste, big cob, Shelf life, Market	89.1
Sweet taste, keeping quality , big cobs	90.6
Sweet taste, keeping quality, retain color	93.8
Sweet taste, maturity period early	96.9
Sweet taste, shelf life, cob size	100.0

Table 3.10: Green maize traits required by farmers in the ideal green maize hybrid

Attribute	**Mean (%)**
Grain yield potential (high)	100
Selling ability (high)	96.6
Grain texture (flint)	98.4
Grain color (white)	96.9
Ear placement (medium)	100
Cob (fat and long)	93.8
Maturity period () early	75.0
Plant height (medium)	84.4
Shelf life (long)	75.0
Roasting quality (non popping)	87.5

The traits that are not liked by farmers are presented in Table 3.11. The major bad attributes of the predominant hybrids are thin and long cobs especially in summer.

Table 3.11: Bad attributes of the predominant market preferred hybrid (SC701) mentioned by farmers

Attributes	Mean percentage
diseases, heat intolerant	51.6
diseases, not uniform cobs	53.1
Drought sensitive, small cobs in summer	54.7
Ear placement high, diseases	56.3
Heat sensitive	59.4
long period of planting, no uniform cobs	60.9
Long season cultivar,	62.5
Long season, heat sensitive	64.1
Long season, require more water, heat intolerance, non- prolific,	65.6
Long thin cobs, Diseases	67.2
Not resistance to heat, many diseases	75.0
Now no uniformity from cobs	76.6
Pests and diseases, doesn't do well in summer	78.1
Pests and diseases, too long stalk	79.7
Poor grain filling under stress condition	81.3
Require high management, and expensive	82.8
Rust, pest (aphids) small cobs MSV	84.4
Rust, small cobs, MSV	85.9
Sensitive to heat, and diseases	87.5
Small cob, diseases	89.1
Small cob, diseases Rust	92.2
Small cobs, uneven maturity, poor germination	93.8
Prone to diseases: Streak virus, down mildew, and rust	95.3
Takes too long to mature	98.4
Thin and long cobs in summer	100.0

Table 3.12: Desirable and undesirable attributes of the second rated hybrid (SR52) mentioned by farmers

Attributes	Mean percentage
Good attributes	
Big and long cob	84.4
Eye catching cob	98.4
Bad attributes	
Late maturity	85.9
Poor keeping quality, no taste,	90.6
poor shelf life	93.8
poor shelf life, tasteless	98.4
Poor taste	100
Poor taste and long maturity period	81.3
Prone to diseases and poor taste	82.8

3.7 Discussion

The results of this study indicated that the age of the farmers ranged from 24 to 66 years. Some farmers had wide experience in farming. In the group discussion even, though the data was not captured, farmers mentioned that they shared their farming expertise with their colleagues. This showed that the older farmers could work independently with sound knowledge gained from this experience, and could provide mentorship to the new entrants.

Farmers owned livestock such as cattle, goats and chickens. They also owned movable assets such as motor vehicles, motor bikes, bicycles and tractors; all this symbolized wealth of the farmers. Movable assets assisted farmers in making farming easier with transport to the fields and buying of inputs. Availability of transport gave them choice of buying inputs where prices were reasonable. From this study it was shown that farmers brought agricultural supplies at Pongola town which is 200 km return and in other countries such as Swaziland. Farmers with transport had a choice of selling green maize where the market prices were favourable. If the market was saturated they loaded green maize and sold it to the pension pay points or sent it to the closest towns such as Nongoma and Mpangeni. They also got hired by other farmers for this reason. Farmers with tractors ploughed their land and also got hired by other farmers.

The correlations analysis of factors in this study indicated a positive relationship between number of cattle, goats and chickens with the return per ha. This indicates that these livestock acted as cash security in the sense that if a farmer had good return from green maize she/he could possibly invest by buying any of these livestock. If a farmer experienced financial difficulties she/he sold any of these livestock and bought production inputs. Therefore the sustainability of the business is achieved.

The allocation of land was equal to female and male farmers. According to the policy of Mjinidi irrigation scheme each farmer leases 10 ha. However, the study indicated that there were farmers who leased as much as 40 ha. It appeared that some farmers made their own arrangements outside of this policy. The policy provides that if farmers failed to utilize land they must release it back to the irrigation scheme. However farmers held on to the land for their relatives or for their children. While doing that they unofficially subleased to other farmers. The subleasing farmer would pay rental to the owner who pays Mjindi irrigation scheme. Usually sugarcane farmers are those who rent big farms. This is a good practice for farmers since less land is left lying unutilized even though they are breaking the policy rules and encourage biasness of land allocation to farmers.

There were no gender differences for land rental, livestock ownership and household assets ownership. Male and female farmers invested in any of these as long as they could afford them. However it was noted from this study that male farmers had more farming equipment, such as motor vehicles, tractors and bicycles which made them utilizes more land (Figure 3.2 and 3.4) than female farmers. This probably also influenced the return per ha to be more (R22 531) for males than (R19 687) female farmers (Table 3.4). The uses of unsold cobs were the same for both groups. They preferred selling dry grains than use as stock feed, and home consumption. What was interesting was that they did harvest the remainder from green maize; therefore there was no total loss of produce even though they got less prices for dry grain than green maize sales. A market study for green maize is really needed because it will identify the size of the market.

Kim et al. (2008) indicated that estimates of maize yield from farm and experimental fields across the African continent are often reported as grain yield. Production difference was compared between male and female farmers in the past four years (Figure 3.4), the results indicated that male farmers produced more than females, but the numbers of hectares being utilized by male farmers were declining (Figure 3.4). Females were almost consistent in their production. However, the difference between the two groups was small. This gender difference in production has an influence on farmers production trends observed in the past four years, which shows a drastic decline in 2010 (Figure 3. 5). One cannot isolate hybrid problem from market problems and crop production management problems which also had negative implication in green maize return. In general these factors can be grouped as the ones that cause production constraints such as suitable for summer production,

A problem of bird's damage at planting was reported by Fanadzo et al. (2010) at Zanyokwe irrigation scheme in the Eastern Cape. This shows that there are many problems which affect farmers in the irrigation schemes which require urgent attention. Therefore, one factor should be considered at time so that a consolidated statement can be drawn to give a direction to farmers. Different disciplines, such as plant breeders, agronomists, horticulturists, food scientists, and agricultural economists are required to solve the raised issues.

This study showed that majority of the farmers planted green maize in March in order to be harvested in July- August when prices are high. Green maize price is high in July-August because it is cold in other areas whilst the base temperatures at Mjindi and Ndumo are high enough to support winter production of maize. However this promotes gluts in the market. Due to that, this study reported a minimum return of R3000 earned by a farmer. From the informal discussions farmers indicated that, with the revenue received from this business, they paid school fees, bought basic needs including food for their families. This shows that the production and marketing of green maize in the study sites contributes to household's foods security and well being.

An informal survey result showed that green maize was planted at the spacing of 0.9 x 0.3m, which resulted to a plant population of about 37000 plants per hectare in both schemes. Green maize marketable ears were sold at R2.00 per cob. This indicates that few self-employed rural folks have the potential to earn R315, 072 over two production cycles per annum. This translates to R26.256 per month if calculated by 12 months. This could be more with good hybrid, high management and good marketing skills. However farmers will not sell everything as green maize and price fluctuations and unforeseen losses may count. The findings of this study agrees with the statement made by Alimi and Alofe (1993), as cited by Kim et al. (2008) that green maize is available at a time when other crops are not ready for harvest, and the resulting higher profit margins are other factors responsible for its popularity. However, Mjindi and Ndumo irrigation schemes benefit more since they plant in winter when other areas in South Africa are experiencing cold and as a result they compete with few or no other green maize growers. It is a great opportunity which allows them to produce two crops in a year. The emphasis of this study was on green maize hybrid model development and farmers indicated the traits they did not like in a green maize hybrid. They mentioned disease problems, thin and long cobs in summer as the traits that need to be improved when breeding green maize hybrids. The ideal hybrid model as required by farmers or the quality of the green maize product should feature the following traits:

1. High ear yield potential
2. High selling ability
3. Flint grain texture
4. White grain color
5. Medium ear placement
6. Fat and long cob
7. Short maturity
8. Medium plant height
9. Long shelf-life and
10. Non-popping during roasting.

The information obtained from the study would be used in developing a selection index for a green maize hybrid which will impact on the adoption of new hybrids and on the profit margins for the farmers. The results show that there is a great potential in green maize business looking at the annual returns per hectare. Farmers could get more return if they can get suitable hybrids for lowland environment and improve on the crop management practices. For example, carefully planned planting schedules should be considered so that crops will not mature at the same stage to avoid an apparent oversupply that results in a price penalty.

3.8 Conclusions and Future Directions

The following conclusions were drawn from the study:

1) The desired agronomic traits for a green maize hybrid are high ear yield, medium ear placement, medium plant height and short growing period.
2) The desired market or quality traits are flint grain texture, white grain color, fat and long cobs, non-popping during roasting (high roasting quality) and long shelf life.
3) The potential annual return per hectare is R21, 109 which translate to total returns of about R300, 000 per household is an indicator of a good enterprise, which is reflected by the ownership of assets by farmers, ranging from livestock to movable assets.
4) Although not significant in all the cases, male farmers had more livestock's, large land and high sales than their female counter parts, indicating that they have a slight advantage
5) Lack of a green maize hybrid suitable for summer production under the lowland conditions at Mjindi and Ndumo appeared to be the major production constraints. Apparent lack of adaptation to the summer environment was reflected by few (12000) cobs that was sold at R2.00. The rest of the cobs were sold at low prices due to its sizes and its weight.

Further studies which pay attention to the marketing, production economics, and risk management, and value addition in green maize production are recommended. Improvements in seed quality would also increase the number of saleable ears per household.

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4 Line by Tester Analysis of Hybrids for Green Maize Traits

4.1 Abstract

Green maize is popular in Africa and other developing countries. There is limited information for use in developing new green maize hybrids. The objectives of this study were to determine the combining ability of advanced inbred maize lines for green maize traits, relationships among traits, and identify new hybrids with potential for green maize production. To generate experimental hybrids 100 F5:6 white grain maize lines were crossed in a Line x Tester mating scheme in 2009. The hybrids with sufficient seed quantities were evaluated for fresh ear yield, ear length, and single ear weight and marketability index (MI) and key agronomic traits at three sites in 2010. Genotypes x environment interaction effects were significant for the four green maize traits. Only a few hybrids such as GMH146 and GMH124 exhibited high performance consistently in at least two sites. Hybrids variation for marketability indices were attributed to differences between the two testers (general combining ability due to male effects) and their interactions with the lines (specific combining ability, i.e., SCA) at all sites. The line main effects (general combining ability due to female effects, i.e., GCA) were also highly significant. Both fresh ear yield and grain yield varied significantly among hybrids as a result of differences between the lines (GCA), testers (GCA) and their interaction effects (SCA), suggesting that both additive and non-additive effects, respectively, were important in conferring the yield. This provides the opportunity for selection from this population to obtain productive inbred lines and exploit heterosis in developing green maize hybrids. The top 15 experimental hybrids with potential for green maize market were identified and selected in each environment. Qualifying 45 hybrids will be tested widely for both quantitative and qualitative attributes in the niche production environments.

4.2 Introduction

Green maize is popular in West Central, East and Southern Africa (Kim et al., 2008). It is used for food and cash security in Africa, and other developing countries such as Brazil and Mexico among others in Latin America and South East Asia. Kim et al. (2008) reported that in many countries in Africa, green maize, is harvested and consumed after roasting or boiling, providing a major source of calories. Fanadzo et al. (2010) indicated that green maize is the most important crop in the small-holder irrigation schemes (SIS) in South Africa, especially in the Eastern Cape Province. However, production in South Africa is not limited to the Eastern Cape. Green maize is produced by small-scale commercial farmers at Mjindi, Ndumo and Tugela Ferry Irrigation Schemes in KwaZulu-Natal (KZN), while large scale commercial production of green maize has been reported at Camperdown and Vryheid in KZN. Fanadzo et al. (2010) reported production of green maize by small-scale commercial farmers at Zanyokwe Irrigation Scheme in the Eastern Cape. Generally winter production of green maize is dominated by the small-scale commercial farmers in the lowland irrigation schemes which provide adequate heat units for maize production during May – October, while summer production has been observed in other regions including Gauteng, where production is predominantly large scale farming.

Production of green maize has also been documented in other countries. For example, Spaner et al. (1996) reported that in Trinidad, maize is grown mainly on mixed subsistence and cash crop and is harvested as green ears for consumption. Production of green maize in Africa has also been reported in Nigeria (Kim et al., 2008). Although not documented or quantified production, sale and consumption of green maize has been observed in many other sub-Saharan African countries.

Despite the fact that green maize is popular in Africa and other developing regions, there is limited literature of the genetics, in particular on the combining ability, of maize germplasm for use in developing new hybrids with the preferred green maize attributes, including the relationships between quantitative and quality traits. For example the relationship between yield and marketability traits has not been reported in the literature. Such information is crucial for setting up a viable breeding programme that aims to develop appropriate and specialty hybrids for the green maize market. As a result of the limited information and research on green maize, there are only a few hybrids that are suitable for green maize production and acceptable to the consumers in South Africa, and perhaps in other regions.

The combining ability of maize inbred lines for green maize traits such as marketability traits has been scarcely reported in the literature. Combining ability is one of the most important concepts in quantitative genetics, which aids in selection of desirable inbreds to be used for development of superior hybrids (Singh et al., 2010). Gopal (1998) indicated that combining ability analysis provides information on the relative importance of additive and non-additive gene action in the manifestation of heterosis. Understanding of combining ability is important because the information can be used to decide on breeding strategy, and on how to organize the maize lines according to heterotic groups and patterns for the effective management of germplasm. Heterosis is described as the superiority of F_1 hybrid performance over some measure of the performance of the parents (Stuber, 1994). On the other hand, a heterotic group is defined as a group of related or unrelated genotypes from the same or different populations which show similar combining ability or heterotic response when crossed with genotypes from other genetically distinct germplasm groups (Melchinger and Gumber, 1998). Heterotic patterns refer to specific pair of two heterotic groups which express high heterosis and consequently high hybrid performance in their crosses (Melchinger and Gumber, 1998). The larger the heterotic patterns between two parental varieties the more genetically diverse they are. Badu-Apraku et al. (2010) reported that knowledge and understanding of heterotic patterns of inbred lines is crucial for improving populations and developing hybrids.

The line x tester analysis is used to estimate the general combining ability (GCA) for lines, testers, and specific combining ability (SCA) for the crosses. Kumar and Bharathi (2009) reported that the line x tester analysis is one of the methods for estimating combining ability and heterosis in maize. Bocanski et al. (2010) reported that crosses between lines do not always produce heterosis; therefore it is necessary to determine the combining abilities of lines in order to identify potential parents for productive hybrids. Jebaraj et al. (2010) reported that line x tester mating design has widely been used for evaluation of inbred lines by crossing them with testers. According to de Rissi and Hallauer (1991), the definition of a “good tester” depends upon the objective of the breeding programme. However, a “good tester” for an inbred-line development programme is the one that correctly classifies and discriminates the relative potential of lines in crosses. The value of any inbred line in hybrid breeding depends on its ability to combine very well with other lines to produce superior hybrids.

Spanner et al. (1996) investigated combining abilities and heterotic patterns among open pollinated varieties and assess correlations among five important traits; time to silking, plant height, grain yield, ear size, and marketable ears per ha. Results indicated that general combining ability was significant for all traits, indicating that additive effects were governing the traits. However, non-additive effects were also important because specific combining ability effects were significant for all traits except ear size (Spanner et al., 1996). Combining ability of the lines that were derived from the population “HYP16” with potential for use in green maize production has not been quantified. This population was developed by combining two lines (A and A’) which are in the same heterotic group A with green maize potential at UKZN. In this study green ear marketability index was used to evaluate hybrids for green maize potential. The components of the index are ear length and fresh ear weight. Additionally, the dry grain yield and desired agronomic traits were investigated because the remaining ears which fail to attract green maize buyers would be used as grain.

The objectives of the current study were as follows:

a) To determine the combining ability of advanced inbred maize lines for ear yield, ear length, single ear weight and marketability;
b) To determine the relationships between marketing ability and desired agronomic traits; and
c) To identify new hybrids with potential for green maize production in different environmental niches in KwaZulu-Natal, in South Africa.

4.3 Materials and Methods

Germplasm and Line X Tester Mating Scheme

Prior to this study 100 inbred lines (inbreds) were derived from the F2:3 population "HYP16", following a pedigree selection in the breeding program at the University of KwaZulu-Natal. Prior to the current study elite tropical inbred parents (Parent A and A') with potential for green maize production were identified based on pedigree information, and were combined to form the F_2 base population (A x A') from which new experimental inbred lines were derived following the pedigree selection. The derived new inbred progenies were then subjected to a line by tester analysis for green maize traits such as ear yield per hectare, marketability index, ear length and single ear weight and the desired agronomic traits. The marketability index is defined as the product of ear length and ear weight because consumers' select green ears at the market based on these traits, plus freshness of the ears. Features of the experimental inbred lines are presented in Appendix 2. Tropical testers PA1 and P1 were used to discriminate the experimental inbreds. These are late maturing tropical lines with proven discrimination capacity under stress and none stress production conditions. The crosses were generated at Makhathini Research Station (Appendix 1) during the winter season in 2009. Staggered planting of the testers (PA1 and P1) was employed. This entailed three planting dates at a weekly interval as follows: on 06 May first male rows (PA1 and P1) were planted, 14th May planting female rows and the last planting of male rows (PA1 and P1) was on the 19th May 2009. A set of 100 F6 white grain maize inbred lines that were generated at the University of KwaZulu-Natal was crossed to generate 186 experimental hybrids which yielded adequate seed for trials in a line x tester (100 lines x 2 testers) mating design scheme.

Experimental Design and Management

Out of the possible 200, only 186 hybrids had sufficient seed for planting in trials. The 186 experimental hybrids were evaluated at Makhathini Research Station (77 m altitude; Latitude 27.39^{0}S; Longitude 32.17^0), Cedara (1066 m altitude; Latitude 29.54^{0}S; Longitude 30.26^{0}E) and Dundee Research Station (1219m altitude Latitude 28^{0}S;

Longitude 30.31^{0}E), during the summer season in 2009/2010. Currently grown maize hybrids: SC701, PAN6777, PAN7M07 and Zama Star were included as control varieties. All experiments were laid out in 19 blocks x 10 plots of alpha lattice designs with 4 replications for Makhathini and two for Cedara and Dundee. Each plot consisted of one row of 5m length. Plants were spaced at 30cm within rows and 90cm between rows. There were two plants per hill, giving a total of 17 plants per plot. The fertilizer was applied at a rate of 250kg MAP (33% P), and 250kg LAN (28%N) per ha. A 250kg MAP (33% P) was broadcast two weeks before planting and the 250kg LAN was used as a side dressing at 6 weeks after planting. Standard cultural practices, including hand planting, hand weeding and application of herbicides was followed at the research sites. All trials were expected to be rain-fed but supplementary irrigation was applied at Makhathini Research Station which is a dry site.

Records and Data Collection

The following traits were recorded in all trials:

1. Cob size (length) – in centimeters from the ear base to the tip of the ear.
2. Grain texture (flint vs. dent) dry grain – a scale of 1-5 where 1 is flint and 4 is dent
3. Plant height - the distance from plant base to the point where the tassel starts to branch was measured.
4. Ear height – distance from the soil to the nod bearing the uppermost ear.
5. Flowering date-tassel emergence was recorded when 50% of the plants had tassels emerged
6. Flowering date - silking date - number of days from planting until the date on which 50% of the plants in a plot had silk 2-3 cm long.
7. Fresh ear yield - weighing all cobs harvested in a plot at milk stage
8. Grain moisture percentage - take ears from same plot, shell and mix the grain, test the moisture percentage using portable moisture tester.
9. Field weight –, the field weight of ears with cobs in kilograms to one decimal place.
10. Total number of ears (EPP) - the total number of ears harvested, excluding secondary ears that are extremely small were recorded.
11. Marketability index - ear length multiplied by ear weight of green cobs.

4.4 Data Analysis

Data were analysed using Proc GLM procedure in SAS following a fixed model for the individual site data, using the model: Y_{ijk}= μ+ b(r) + t + l +tl + e_{ijk}; And for the across sites data using the model:

$Y_{ijkl} = \mu + s_i + r_j(s_i)+b(r_j*s_i) + t + l+ tl+ ts_i +ls + tls + e_{ijkl}$

Where y_{ijk} = observed hybrid response;

μ= overall trial mean;

s_i = Site main effects;

b (r_j*s_i) = effect of blocks within replications (r) and sites (s);

t = tester main effects;

L = line main effects;

tl = line x testers interaction effects;

ts and ls = sites x tester and site x line interaction effects;

tls = line x tester x site interaction effects;

e_{ijkl} is the experimental error.

The hybrid variation was partitioned into tester and line parent main effects giving two independent estimates of GCA effects which are attributable to the testers (GCA_t) and lines (GCA_l), respectively, while the tester x line interaction estimates the SCA effects (Halluaer and Miranda, 1988).

The GCA effects for the testers and lines were estimated according to Kearsey and Pooni (1996) as follows:

$GCA_l = X_l - \mu$ and $GCA_t = X_t - \mu$ where GCA_l and GCA_t =GCA of line and tester parents respectively; X_l and X_t = mean of the line and tester parents, respectively; μ= overall mean of all crosses.

The standard errors (SE) of for tester GCA and line GCA effects were calculated (Dabholkar, 1992) as follows:

$GCASE_t = \sqrt{}(MSE/s*r*l)$, $GCASE_l = \sqrt{}MSE/S*r*t)$ where MSE= mean square error, r = number of replications; l and t number of lines and tester parents, respectively.

The SCA effects of the crosses were estimated according to Kearsey and Pooni, (1996): as follows: $SCA_x = X_x – E (X_x) =-[GCA_l+ GCA_t + \mu]$, where: SCA_x = SCA effects of the two parents in the cross; X_x = observed mean value of the cross; E (X_x) = expected value of the cross based on the GCA effects of the two parents involved; GCA_l and GCA_t = GCA of the line and tester parents, respectively.

The standard error (SE) of the SCA effects was calculated according to Dabholkar (1992) as follows: $SE=\sqrt{(MSE/rs)}$ where MSE =mean square error; r = number of replications=number of sites.

4.5 Results

Genotype x Environmental Interaction Effects

Only hybrids that were planted at all the three sites were included in the combined analysis of variance, and rank analysis. The hybrid x site interaction effects was highly significant for all the traits except marketability index (Table 4.1). The Site X Line interaction effects was significant for three traits (ear yield, ear length and marketability index) except single ear weight. The Site X Tester interaction effects were highly significant for all traits across the sites. The model accounted for 79% to 92% of the variation as reflected by R^2, while the coefficient of variation (CV) ranged between 7% and 24%.

Table 4.1: Mean squares for green maize traits across three sites

Source	DF	Ear Yield		Ear Length		Single Ear Weight		Marketability Index	
		MS	Pr > F	MS	Pr > F	MS	Pr > F	MS	Pr > F
Site	2	413.13	<.0001	24.71	<.0001	2764171.05	<.0001	1332.96	<.0001
Replication	1	44.53	<.0001	0.57	0.6319	274002.89	<.0001	166.12	<.0001
Block(Site x Rep)	110	3.08	<.0001	6.04	<.0001	12550.58	<.0001	7.85	<.0001
Hybrid	128	5.45	<.0001	5.37	<.0001	18092.11	<.0001	11.88	<.0001
Line GCA	70	1.94	<.0001	4.46	0.0005	7950.91	0.0006	5.27	<.0001
Tester GCA	1	376.75	<.0001	174.83	<.0001	1110118.77	<.0001	767.38	<.0001
Line X Tester (SCA)	57	2.08	<.0001	2.92	0.1996	8744.36	0.0002	4.74	0.0005
Site X Hybrid	256	1.16	0.0011	4.12	<.0001	5897.29	0.013	2.99	0.1277
Site X Line GCA	140	1.17	0.0041	3.94	0.0006	4941.97	0.2497	98.60	<.0001
Site X Tester GCA	2	26.45	<.0001	53.83	<.0001	151876.46	<.0001	38.88	<.0001
Site X Line X Tester	114	0.90	0.2196	3.38	0.0219	4987.50	0.2432	3.14	0.0825
Error	276	0.80		2.48		4487.87		2.54	
R^2 (%)		92.42		0.79		0.91		0.91	
CV (%)		19.2		7.14		23		24.6	
Mean		4.6485		22.05		290.25		6.45	

Combining ability effects for green maize traits

The hybrids were highly significantly different for all traits (Table 4.1). The line main effects were significantly different for all the traits. The tester main effects were highly significantly different for all traits across the sites (Table 4.1). The Line x Tester interaction effects was significant for three traits except Ear Length. The GCA of lines for green maize traits is presented in Table 4.2. The following lines had significant positive GCA effects for all traits studied, across the three sites: Line GML34, GML95, GML68 and GML105. GML94, GML93 and GML99 had significant positive GCA for three traits except Ear Length. GML18 and GML85 had significant positive GCA for Single Ear Weight and Marketability Index; GML98 had significant positive GCA for Ear Yield and Marketability Index. GML38 had significant positive GCA for Ear Yield and Ear Length. Lastly GML100 had significant positive GCA for Ear Yield and Single Ear Weight. The following lines exhibited significant positive GCA effects for one trait Line: GML75, Ear Yield, GML102 and GML103, Ear Length. Out of 30 lines studied only nine lines displayed desirable GCA effects for marketability Index across the sites: Line: GML64, GML2, GML3 GML78, GML44 GML67, GML30, GML27 and GML28. On the other hand 12 lines displayed undesirable GCA effects for the same trait across the sites lines: GML2, GML3, GML78, GML19, GML44, GML67, GML30, GML27, GML28, GML23, GML12 and GML43.

The GCA effects of inbred testers for green maize traits across the three sites are presented in Table 4.3. Results show that P1 was the superior tester that conferred higher performance in hybrids than PA1 because it had positive GCA for all the green maize traits, while PA1 had negative values. Inbred tester PA1 showed good GCA effects for Ear Weight. Generally, P1 had good means in all green maize traits but its GCA was lower than PA1.

The specific combining ability effects of the hybrids are presented in the Table 4.4. It is indicated that the best seven hybrids had significant positive SCA effects for marketability index. The bottom five hybrids also had significant but negative SCA effects for the same trait. Almost all the bottom 10 hybrids displayed negative or neutral SCA effects for ear yield, while none of the top 15 hybrids had significant SCA effects for ear length.

Table 4.2: Means *inter se* and GCA effects of selected maize inbred lines with the best and worst marketing index across three sites

Line	Ear Yield (t/ha)			Ear Length (cm)			Single Ear Weight (g)			Marketability Index (cm x g)		
	Mean	GCA		Mean	GCA		Mean	GCA		Mean	GCA	
GML34	6.35	**1.63**	**	24.92	**2.80**	**	402.47	**108.92**	**	9.95	**3.41**	**
GML95	6.52	**1.80**	**	23.32	**1.20**	*	396.82	**103.27**	**	9.13	**2.59**	**
GML94	6.23	**1.51**	**	22.83	0.71		367.50	**73.95**	**	8.45	**1.91**	**
GML68	5.52	**0.80**	**	23.60	**1.48**	**	333.62	**40.07**	*	8.14	**1.60**	**
GML105	5.51	**0.79**	**	23.71	**1.59**	**	333.35	**39.80**	*	7.96	**1.42**	**
GML99	5.75	**1.03**	**	22.17	0.05		354.75	**61.20**	**	7.92	**1.38**	**
GML93	5.55	**0.83**	*	22.88	0.76		346.57	**53.02**	*	7.88	**1.34**	*
GML18	4.88	0.16		22.75	0.63		346.12	**52.57**	*	7.85	**1.31**	*
GML85	4.93	0.21		22.02	-0.10		354.99	**61.44**	**	7.64	**1.10**	*
GML98	5.42	**0.70**	*	22.65	0.53		322.85	29.30		7.48	**0.94**	*
GML38	5.35	**0.63**	*	23.38	**1.26**	*	318.67	25.12		7.41	0.87	
GML97	5.35	**0.63**	*	22.92	0.80		316.97	23.42		7.38	0.84	
GML100	5.87	**1.15**	**	21.77	-0.35		333.02	**39.47**	*	7.25	0.71	
GML75	5.25	**0.53**	*	22.75	0.63		309.73	16.18		7.03	0.49	
GML102	5.07	0.35		23.17	**1.05**	*	302.18	8.63		7.02	0.48	
GML103	4.88	0.16		23.58	**1.46**	**	294.55	1.00		7.00	0.46	
GML49	4.13	**-0.59**	*	21.92	-0.20		259.92	-33.63		5.77	-0.77	
GML66	4.09	**-0.63**	*	21.65	-0.47		261.97	-31.58		5.71	-0.83	
GML64	3.98	**-0.75**	*	22.69	0.57		252.67	**-40.88**	*	5.65	-0.89	
GML2	3.98	**-0.75**	*	22.49	0.37		249.85	**-43.70**	*	5.59	**-0.95**	*
GML3	3.98	**-0.75**	*	22.42	0.30		248.03	**-45.52**	*	5.50	**-1.04**	*

Line	Ear Yield (t/ha)			Ear Length (cm)			Single Ear Weight (g)			Marketability Index (cm x g)		
	Mean	GCA		Mean	GCA		Mean	GCA		Mean	GCA	
GML78	4.03	**-0.69**	*	22.00	-0.12		252.32	**-41.23**	*	5.48	**-1.06**	*
GML19	4.00	**-0.72**	*	21.04	**-1.08**	*	258.31	**-35.24**	*	5.45	**-1.09**	*
GML44	3.98	**-0.74**	*	21.58	-0.54		244.93	**-48.62**	*	5.33	**-1.22**	*
GML67	4.00	**-0.72**	*	21.67	-0.45		243.15	**-50.40**	*	5.29	**-1.25**	*
GML30	3.93	**-0.80**	**	21.78	-0.34		247.66	**-45.89**	*	5.28	**-1.27**	*
GML27	3.85	**-0.87**	**	21.30	-0.82		238.19	**-55.36**	*	5.22	**-1.32**	*
GML28	4.03	**-0.69**	*	21.59	-0.53		235.98	**-57.58**	*	5.18	**-1.37**	*
GML23	4.03	**-0.69**	*	21.00	**-1.12**	*	241.98	**-51.57**	*	5.17	**-1.37**	*
GML12	3.97	**-0.75**	*	20.96	**-1.16**	*	228.89	**-64.66**	**	4.81	**-1.73**	**
GML43	3.68	**-1.05**	**	20.49	**-1.63**	**	226.53	**-67.02**	**	4.68	**-1.87**	**
Statistics												
LSD /GCASE (0.05)	1.759	0.257		3.322	0.455		131.880	19.339		3.135	0.460	

*, ** Data significant at P<0.05 and P<0.01, respectively.

Table 4.3: Means and GCA effects of the inbred testers for green maize traits across three sites

Tester	Ear Yield (t/ha)			Ear Length (cm)			Ear Weight (g)			Marketing Index (cm x g)		
	Mean	GCA	se	Mean	GCA	se	Mean	GCA	se	Mean	GCA	se
PA1	3.75	-0.83**	0.047	21.41	-0.586**	0.084	241.35	-45.06**	3.561	5.16	-1.19**	0.085
P1	5.41	0.83**	0.044	22.59	0.586**	0.077	331.46	45.06**	3.269	7.54	1.19**	0.078
LSD0.05	0.127			0.224			9.515			0.226		

*, ** Data significant at P<0.05 and P<0.01, respectively.

Table 4.4: Specific combining ability effects of hybrids for green maize traits across three sites

Hybrid	Specific Combining Ability							
	Ear Yield (t/ha)		Ear Length cm)		Ear weight (g)		Marketability Index	
Top 15								
GMH125	-0.20		1.13		-2.31		3.09	**
GMH108	0.55		0.15		26.61		2.95	**
GMH18	0.93	*	0.24		103.63	**	2.45	**
GMH124	0.86	*	-0.12		78.83	*	1.84	*
GMH3	1.31	**	-0.09		69.75	*	1.54	*
GMH147	0.40		-0.17		27.48		1.39	*
GMH146	0.82	*	-0.02		64.08	*	1.36	*
GMH120	0.98	*	0.25		53.24		1.25	
GMH75	0.83	*	0.58		45.04		1.19	
GMH139	0.81	*	0.75		41.86		1.16	
GMH102	0.67		0.53		38.71		1.04	
GMH5	0.01		0.74		2.83		0.98	
GMH155	0.30		0.17		26.09		0.90	
GMH1	0.52		0.31		33.64		0.87	
GMH62	0.44		-0.03		40.44		0.87	
Bottom 10								
GMH122	-0.83	*	-0.58		-45.05		-1.20	
GMH180	-0.83	*	-0.59		-45.05		-1.20	
GMH168	-0.84	*	-0.58		-45.05		-1.20	
GMH183	-0.84	*	-0.59		-45.05		-1.20	
GMH20	-0.89	*	1.74	*	-53.25		-1.27	
GMH106	-1.30	**	0.08		-69.78	*	-1.54	*
GMH26	-0.86	*	0.12		-78.68	*	-1.85	*
GMH11	-0.02		-0.27		4.06		-2.20	**
GMH118	-0.95	*	-0.25		-103.64	**	-2.46	**
GMH56	-0.83	*	0.02		-64.08	*	-7.92	**
SE	0.36		0.64		27.35		0.65	

4.6 Rank of hybrids across sites

Ear Yield

Means and ranks of hybrids for ear yield traits across the sites are presented in Table 4.5. Hybrids were ranked based on mean ear yield in each site. Hybrids with highest mean ear yield were given highest rank positions in each site. Average ranking for hybrids was calculated across three sites. The average mean rank was then used to select top 15 hybrids. Three hybrids were in the top 10 average rank position across the sites. There were hybrids: GMH146, GMH124 and GMH113. The bottom 10 hybrids for ear yield were also presented in Table 4.5.

Table 4.5: Mean and rank of hybrids for ear yield (t /ha) across three sites

Hybrid	Makhathini		Dundee		Cedara		Average	
Name	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Top 15 hybrids								
GMH146	5.34	4	8.15	2	8.22	6	7.24	4
GMH124	5.00	6	7.70	4	8.07	9	6.92	6
GMH113	4.78	9	8.15	1	7.80	13	6.91	8
GMH167	4.74	12	7.20	8	6.87	28	6.27	16
GMH147	5.06	5	7.10	11	6.69	34	6.28	17
GMH115	4.23	21	6.25	29	8.85	2	6.44	17
GMH177	4.83	7	7.60	6	6.41	40	6.28	18
GMH136	4.11	23	6.80	17	7.53	16	6.15	19
GMH130	3.76	32	8.10	3	7.18	22	6.35	19
GMH139	3.48	41	6.85	14	8.74	3	6.36	19
GMH155	4.52	14	6.00	40	8.67	4	6.40	19
GMH133	4.74	11	6.20	31	7.41	18	6.12	20
GMH142	3.77	31	7.60	5	6.90	26	6.09	21
GMH108	4.26	20	6.85	13	6.74	31	5.95	21
GMH120	3.09	58	7.15	10	9.21	1	6.48	23
GMH169	3.13	54	7.30	7	8.10	8	6.18	23
GMH170	3.36	46	6.80	19	8.56	5	6.24	23
GMH176	3.74	33	6.50	26	7.55	15	5.93	25
GMH148	3.99	26	6.10	35	7.76	14	5.95	25
GMH180	4.66	13	5.95	42	7.28	20	5.96	25
Bottom 10 hybrids								
GMH56	2.28	97	4.00	119	3.56	113	3.28	110
GMH12	2.68	84	3.55	125	2.87	124	3.03	111
GMH71	0.96	127	4.60	100	3.61	110	3.06	112
GMH27	1.39	120	4.15	113	3.73	105	3.09	113
GMH20	0.25	129	4.45	106	3.77	104	2.82	113

Hybrid	Makhathini		Dundee		Cedara		Average	
Name	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
GMH26	1.02	126	3.85	123	4.23	92	3.03	114
GMH42	1.66	114	4.50	104	1.76	129	2.64	116
GMH7	1.67	113	4.15	116	2.70	126	2.84	118
GMH46	0.95	128	4.10	117	3.39	116	2.81	120
GMH28	1.37	121	2.95	129	3.30	119	2.54	123
Mean	3.00		5.58		5.46		4.65	
LSD	1.682		1.554		2.063		1.759	
CV(%)	28.14		14.23		18.95		19.20	

Ear Length

The mean and rank of hybrid for Ear Length across the sites is presented in Table 4.6. In this case hybrids were ranked based on mean Ear Length across the sites. Average ranks for the best top 15 hybrids selected for Ear Length ranged from 6 to 37 positions. Only two hybrids exhibited top 10 rank positions, Hybrid: GMH130 and GMH141. The bottom 10 hybrids for Ear Length are also presented on the Table 4.6. Its ranking positions across the sites ranged from 99 to 113.

Table 4.6: Mean and rank of hybrids for ear length (cm) across sites

Hybrid	Cedara		Makhathini		Dundee		Average	
Name	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
				Top 15 hybrids				
GMH130	23.68	11	26.23	2	25.28	4	25.06	5.7
GMH141	23.54	13	25.41	8	24.56	8	24.50	9.7
GMH139	23.69	10	24.00	29	24.93	5	24.21	14.7
GMH102	24.91	2	25.47	7	22.89	40	24.42	16.3
GMH161	23.05	24	24.41	21	24.12	12	23.86	19.0
GMH152	23.22	20	24.64	18	22.99	38	23.62	25.3
GMH167	21.89	66	25.01	9	26.12	3	24.34	26.0
GMH160	23.46	16	24.52	20	22.72	43	23.57	26.3
GMH133	22.05	61	25.98	4	23.94	15	23.99	26.7
GMH114	23.40	17	24.81	17	22.49	52	23.56	28.7
GMH155	28.65	1	21.49	86	24.64	6	24.93	31.0
GMH134	22.13	59	24.93	13	23.35	32	23.47	34.7
GMH111	22.68	38	22.71	56	24.09	13	23.16	35.7
GMH185	22.48	46	22.50	63	26.41	1	23.80	36.7
GMH184	24.30	5	21.12	96	24.34	11	23.25	37.3
				Bottom 10 hybrids				
GMH128	21.45	79	20.72	100	19.50	118	20.56	99.0
GMH122	20.09	112	22.20	70	19.43	119	20.57	100.3
GMH12	20.80	101	21.70	81	19.27	120	20.59	100.7
GMH15	20.58	103	20.46	107	20.78	98	20.61	102.7
GMH32	21.28	87	18.59	126	20.40	103	20.09	105.3
GMH42	17.80	129	21.99	74	18.34	128	19.38	110.3
GMH27	21.36	82	18.21	128	19.14	122	19.57	110.7
GMH28	19.29	123	20.40	112	20.30	105	20.00	113.3
GMH19	20.49	104	19.91	117	19.26	121	19.89	114.0
GMH70	18.53	126	19.86	119	18.62	127	19.00	124.0
Mean	21.83		22.28		22.03		22.05	
LSD	2.399		4.161		2.540		3.322	
CV(%)	5.51		9.37		5.81		7.14	

Single Ear Weight

The mean and rank of hybrids for Single Ear Weight trait across the sites is displayed on Table 4.7. Hybrids were ranked based on mean single ear weight across the sites. Only two hybrids exhibited top 10 positions: Hybrid GMH146 and GMH 124. Bottom 10 hybrids for single ear weight are also presented in Table 4.7. Its ranking positions across the sites ranged from 104 to 122.

Marketability indices

The mean and rank for Marketability Indices across three sites are presented in Table 4.8. Hybrids were ranked based on mean Marketability indices in each site. Hybrids with highest mean Marketability indices mean were given high rank positions in each site. Average ranking for hybrids was calculated across three sites. The average mean rank was then used to select best top 15 hybrids. Hybrids were selected base on the average rank value across the sites. The lower the rank value the better the hybrid. Average rank mean value ranged from 5 to 27. Hybrids GMH146 and GMH124 were in the highest rank positions (1 and 2).

Table 4.7: Mean and rank of hybrids for single ear weight (g) across three sites

Hybrid	Cedara		Makhathini		Dundee		Average	
Name	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
				Top 15 hybrids				
GMH146	517.15	6	252.59	5	579.07	2	449.60	4.3
GMH124	507.95	8	247.31	6	573.50	3	442.92	5.7
GMH120	572.84	1	197.46	27	452.20	17	407.50	15.0
GMH165	492.41	11	206.51	21	435.17	23	378.03	18.3
GMH145	486.67	13	240.57	8	408.52	36	378.59	19.0
GMH147	417.70	34	213.82	18	521.82	7	384.45	19.7
GMH139	545.29	3	203.34	23	410.00	35	386.21	20.3
GMH177	404.26	39	237.21	12	497.27	11	379.58	20.7
GMH121	468.26	17	217.54	16	415.06	30	366.95	21.0
GMH155	541.76	4	236.42	13	392.61	47	390.26	21.3
GMH167	428.76	28	193.73	29	504.33	9	375.61	22.0
GMH180	457.01	19	239.63	10	403.51	41	366.71	23.3
GMH113	489.73	12	175.08	43	456.99	16	373.93	23.7
GMH134	430.30	26	174.64	45	589.85	1	398.26	24.0
GMH143	360.58	52	202.06	24	530.75	6	364.46	27.3
				Bottom 10 hybrids				
GMH51	191.29	123	124.36	103	333.85	86	216.50	104.0
GMH2	342.71	63	65.68	126	238.07	125	215.49	104.7
GMH65	258.06	96	93.51	118	286.31	113	212.62	109.0
GMH43	179.98	124	77.19	124	328.01	90	195.06	112.7
GMH46	213.44	116	115.10	110	273.46	118	200.66	114.7
GMH7	167.80	126	116.32	109	293.25	109	192.46	114.7
GMH27	233.92	104	97.46	116	138.81	128	156.73	116.0
GMH56	222.60	112	97.53	115	242.21	123	187.44	116.7
GMH42	109.03	129	121.63	105	275.18	117	168.62	117.0
GMH28	209.29	117	79.14	123	199.02	127	162.48	122.3
Mean	341.45		158.64		370.64		290.25	
LSD	128.543		81.125		174.125		131.879	
CV(%)	18.89		25.67		23.58		23.00	

Table 4.8: Mean and rank of hybrids for marketability indices across three sites

Hybrid	Cedara		Dundee		Makhathini		Average	
Name	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**
			Top 15 hybrids					
GMH146	11.77	6	12.78	6	5.90	2	10.15	4.7
GMH124	11.37	8	13.39	3	5.21	12	9.99	7.7
GMH139	12.78	3	10.07	20	4.96	16	9.27	13.0
GMH120	13.17	2	10.20	17	4.40	29	9.26	16.0
GMH155	15.65	1	9.63	33	4.93	17	10.07	17.0
GMH130	10.59	15	14.35	1	4.19	40	9.71	18.7
GMH167	9.44	33	12.79	5	4.78	20	9.00	19.3
GMH177	9.23	40	11.85	10	5.43	9	8.83	19.7
GMH145	11.07	11	9.42	37	5.08	14	8.52	20.7
GMH134	9.58	32	13.58	2	4.33	34	9.16	22.7
GMH147	9.26	39	12.24	9	4.60	25	8.70	24.3
GMH121	10.51	18	9.35	38	4.89	18	8.25	24.7
GMH133	10.13	23	9.76	29	4.69	23	8.19	25.0
GMH180	9.96	24	9.01	45	5.52	7	8.16	25.3
GMH102	10.38	19	9.52	36	4.50	26	8.13	27.0
			Bottom 10 hybrids					
GMH32	6.37	84	5.06	123	2.04	116	4.49	107.7
GMH46	4.72	107	5.45	120	2.82	100	4.33	109.0
GMH65	5.41	92	5.85	118	2.01	117	4.42	109.0
GMH43	3.83	123	7.07	90	1.60	123	4.17	112.0
GMH56	5.28	98	4.76	127	2.26	113	4.10	112.7
GMH7	3.57	126	6.55	103	2.34	111	4.15	113.3
GMH70	4.20	117	6.01	116	2.20	114	4.14	115.7
GMH27	5.15	100	2.40	129	1.72	122	3.09	117.0
GMH42	1.87	129	4.99	124	2.82	99	3.23	117.3
GMH28	4.03	120	3.81	128	1.60	124	3.15	124.0
Mean	7.55		8.27		3.53		6.45	
LSD	3.16		4.004		2.033		3.134	
CV(%)	21.04		24.30		28.90		24.68	

4.7 Best hybrids selected for green maize potential on the basis of stability of marketability index across three sites

The best 30 hybrids with superior marketing ability indices across three sites with a potential for green maize production is presented in Table 4.9. Green maize traits have been described as Ear Yield, Ear Length, Single Ear Weight and Marketability Index. Each hybrid has been ranked base on individual trait means across the sites. All hybrids were given rank positions based on each trait mean across Dundee, Makhathini and Cedara. Thereafter the top 30 hybrids were ranked based on marketability (product of Ear Length x Ear Weight) index mean. Some hybrids displayed their potential to be selected as green maize in more than one trait across the three sites. Hybrids GMH129, GMH126 and GMH 146 and GMH171 were selected for Ear Yield, Ear Weight and Marketing ability Index across three sites. Hybrids GMH105, GMH172 and GMH149 were selected for Ear Weight and marketability index across the three sites. Hybrid GMH124 displayed the same top rank position for both Ear Yield and Ear Weight. Hybrids GMH181, GMH147 and GMH112 were selected for Ear Yield trait across the sites. Only three hybrids selected for Ear Length traits, hybrid: GMH167, GMH133 and GMH102.

Table 4.9: The best 30 hybrids with superior marketability index and potential for green maize production across three sites

Hybrid	Ear Yield		Ear Length		Ear Weight		Marketability index	
	Mean (t/ha)	Rank	Mean (cm)	Rank	Mean (g)	Rank	Mean (g x cm)	Rank
GMH129	5.80	2	20.61	105	287.25	1	6.05	1
GMH146	5.34	4	22.62	60	252.59	5	5.90	2
GMH105	4.30	18	20.41	110	274.69	2	5.79	3
GMH172	2.20	101	21.31	91	268.45	3	5.75	4
GMH149	4.21	22	21.84	77	254.07	4	5.63	5
GMH126	6.33	1	23.72	34	240.18	9	5.57	6
GMH180	4.66	13	23.26	46	239.63	10	5.52	7
GMH135	4.34	17	22.40	67	238.66	11	5.45	8
GMH177	4.83	7	22.86	52	237.21	12	5.43	9
GMH171	4.79	8	21.02	98	241.48	7	5.36	10
GMH75	3.59	38	23.46	41	224.42	14	5.26	11
GMH124	5.00	6	19.70	120	247.31	6	5.21	12
GMH168	4.47	15	23.32	44	219.43	15	5.09	13
GMH145	3.73	35	20.12	116	240.57	8	5.08	14
GMH131	4.28	19	24.26	24	205.83	22	5.03	15
GMH139	3.48	41	24.00	29	203.34	23	4.96	16
GMH155	4.52	14	21.49	86	236.42	13	4.93	17
GMH121	3.73	34	22.81	54	217.54	16	4.89	18
GMH108	4.26	20	24.20	26	199.53	26	4.83	19
GMH167	4.74	12	25.01	9	193.73	29	4.78	20
GMH152	4.06	24	24.64	18	190.26	30	4.71	21
GMH183	4.06	25	22.37	68	208.09	20	4.70	22
GMH133	4.74	11	25.98	4	175.01	44	4.69	23
GMH181	5.48	3	22.25	69	214.96	17	4.64	24
GMH147	5.06	5	21.14	94	213.82	18	4.60	25
GMH102	3.81	30	25.47	7	177.32	39	4.50	26
GMH140	2.98	66	20.66	103	208.56	19	4.42	27
GMH112	4.78	10	22.10	73	199.94	25	4.41	28
GMH120	3.09	58	22.99	50	197.46	27	4.40	29
GMH1	2.93	71	23.78	33	183.99	36	4.39	30
Mean	4.65		22.05		290.25		6.45	
LSD	1.759		3.322		131.879		3.134	
CV(%)	19.20		7.140		23.00		24.60	

Performance of selected hybrids at individual sites

Dundee

The data in Appendix 3 indicate that hybrids containing PA1 as the tester were among the top 15 and dominated the top 5 position at Dundee. At least 9 hybrids out-yielded the control SC701; however, the SC701 out-yielded the other commercial standard check hybrids. The hybrids GMH107, GMH180, and GMH144 were among the top 15 and had the best marketing ability indices; all these hybrids included the P1 as a parent. GMH180 had the highest ear weight while GMH144 had the longest ears. Days to flowering of the hybrids ranged from 63 to 67 days. Standard checks were within the range, however PA1 x P1 (a cross between the two testers) flowered earlier than all the hybrids. All the top hybrids exhibited semi-dent (score of 3) to fully dent grain texture (score of 5). All the hybrids exhibited prolificacy including the standard check hybrid SC701. The hybrids GMH180 and SC701 (22%) had a higher grain moisture percentage than the rest of the hybrids and other check hybrids.

Cedara

The data in Appendix 4 indicate that the top 15 hybrids at Cedara involved the tester P1 and only one hybrid involved PA1. The line GML94 combined very well with both testers and both its hybrid progenies appeared in the top 15. All hybrids in the top 15 were at least 35% better than the control SC701 with respect to ear yield. The mean ear yield ranged between 7 and 9 t/ha, while all the top hybrids exhibited semi-dent to fully dent grain texture. The hybrid GMH155 had the longest ear at Cedara. In general, all the experimental hybrids flowered around 80 days. Other standard commercial hybrids yielded above the green maize standard check (SC701) but all of them were outperformed by the top 15 experimental hybrids. Hybrids GMH115 and GMH124 had the highest (22%) grain moisture percentage.

Makhathini

At Makhathini, hybrids were evaluated for both green and dry ear yield. The data in Appendix 5 indicate that at Makhathini predominantly hybrids involving P1 were in the top 15 for green ear yield only. One hybrid involving PA1 (GMH91) take the pole position and two other PA1 test crosses were among the top 15. These hybrids were at least 89% better than SC701 with respect to ear yield. The mean fresh ear yield ranged between 10 and 13 t/ha. The hybrid GMH58 which included PA1 as parent had better marketing ability index (132%) and the highest ear weight (467 g). The hybrid GMH115 had the longest ears at Makhathini (Appendix 5)

The data in Appendix 6 indicate that most of the hybrids in the top 10 for the dry ear yield except one were P1 progenies at Makhathini. The mean yield of the top 15 hybrids was between 4 and 6 t/ha. The standard check hybrid SC701 was the lowest yielder (1/ha). Therefore, experimental hybrids were at least 200% better than the control SC701. All hybrids flowered between 59 and 65 days at Makhathini. Hybrid GMH180 had the highest ear weight (221g) and all hybrids exhibited prolificacy. The ear height of the top 15 hybrids was between 94 cm and 123 cm, with ear position between 0.4 and 0.5.

4.8 Relationships among traits

The Table 4.10 shows the correlation coefficients among green maize traits in hybrids at Dundee. Ear yield was negative and significantly correlated to anthesis date, also positive and highly significantly correlated with ear height, ear position and ear per plant. Ear length was positive and high significantly correlated with ear yield. Ear length was also negative, significantly correlated with anthesis date and positive significantly correlated with plant height. Ear weight was positive, high significantly correlated with grain yield, plant height and ear per plant. Ear weight was negative high significantly correlated with anthesis date. Marketing ability was positive and highly significantly correlated with grain yield, plant height and number of ears per plant. Marketing ability was negative and significantly correlated with anthesis date and also negative significantly correlated with ear position.

Table 4.10: Correlation coefficients (r) between green maize and agronomic traits at Dundee

Parameter		Ear yield	Anthesis dates (days)	Plant height (cm)	Ear height (cm)	Ear position (ratio)	No. of ears per plant
Ear yield	r value	1	-0.399	0.33838	0.05502	-0.22345	0.53327
	Probability		<.0001	<.0001	0.3816	0.0003	<.0001
Ear Length (cm)	r value	0.49844	-0.21172	0.20075	-0.00674	-0.16075	0.13093
	Probability	<.0001	0.0007	0.0013	0.9147	0.0101	0.0367
Single Ear Weight (g)	r-value	0.85009	-0.35371	0.27921	0.085	-0.14497	0.44845
	Probability	<.0001	<.0001	<.0001	0.176	0.0206	<.0001
MI	r-value	0.86437	-0.34709	0.28825	0.0665	-0.16858	0.41112
	Probability	<.0001	<.0001	<.0001	0.2901	0.007	<.0001

MI = marketing index

The Table 4.11 shows the correlations between the green maize and agronomic traits measured in hybrids at Makhathini. Ear yield was negatively and significantly correlated with anthesis date. Ear yield was positive and significantly correlated with plant height and ear height. Ear weight was positive and significantly correlated with ear yield (Table 4.11).

Table 4.11: Correlation coefficients (r) between green maize and agronomic traits at Makhathini

		Ear yield	Anthesis dates (days)	Plant height (cm)	Ear height (cm)	Ear position
Ear yield (t/ha)	r-value	1	-0.15471	0.20507	0.19697	0.04991
	Prob.		0.0037	0.0001	0.0002	0.3511
EPP	r-value	0.50428	-0.20304	0.04202	0.07844	0.04465
	Prob.	<.0001	0.0001	0.432	0.1419	0.4036
Ear Weight	r-value	0.48422	-0.06751	0.11695	0.23584	0.14563
	Prob.	<.0001	0.213	0.0306	<.0001	0.007

EPP = ears per plant

4.9 Frequency distribution of hybrids for green maize traits

Ear yield

Cedara (site C) was the highest grain yielding environment compared to Dundee (site B) and Makhathini (site A) (see Figures 4.1, 4.2, and 4.3). The maximum mean yield at Makhathini was 6 t/ha, Dundee was 8 t/ha and Cedara was 9 t/ha. However most of the hybrids yielded 6 t/ha at Dundee (B) and Cedara (C) while at Makhathini (A) most of the hybrids yielded 3 t/ha. At all the three sites a continuous distribution of the hybrids was observed for ear yield.

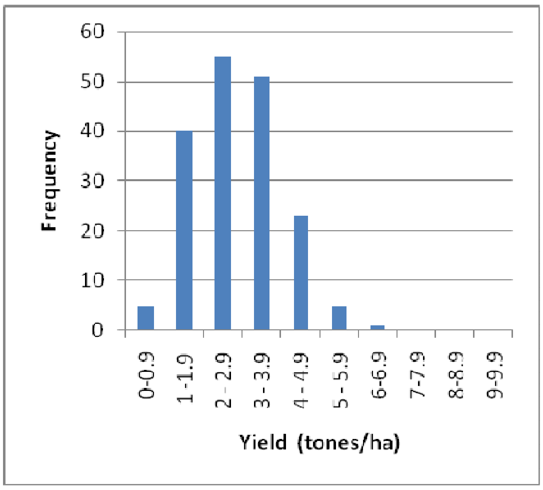

Figure 4.1: Grain yield of hybrids at site A

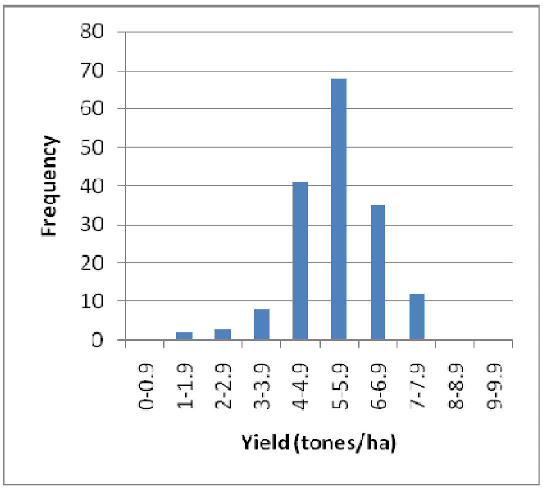

Figure 4.2: Ear yield of hybrids at site B

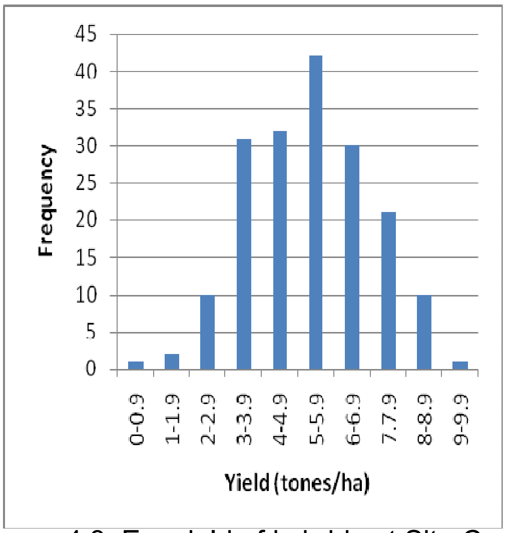

Figure 4.3: Ear yield of hybrids at Site C

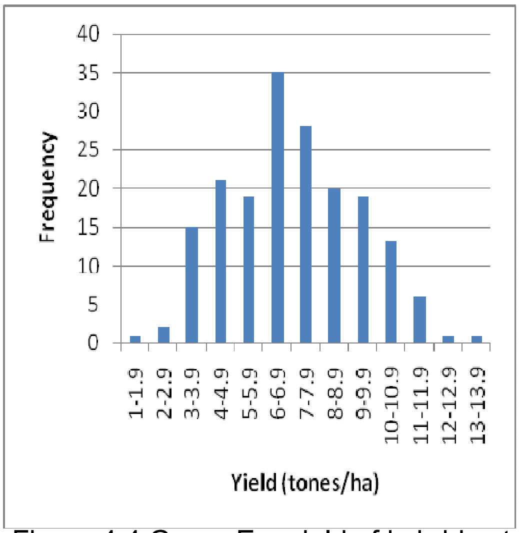

Figure 4.4:Green Ear yield of hybrids at site A

Ear length

The majority of the hybrids had long ears at Makhathini (24 cm) and Dundee (24 cm) while at Cedara most hybrids were 22 cm on average. At both Makhathini and Dundee ear length ranged between 17 cm and 29 cm, while at Cedara it ranged between 17cm and 26 cm (Figures 4.5, 4.6 and 4.7). The distribution was normal and continuous at the three sites.

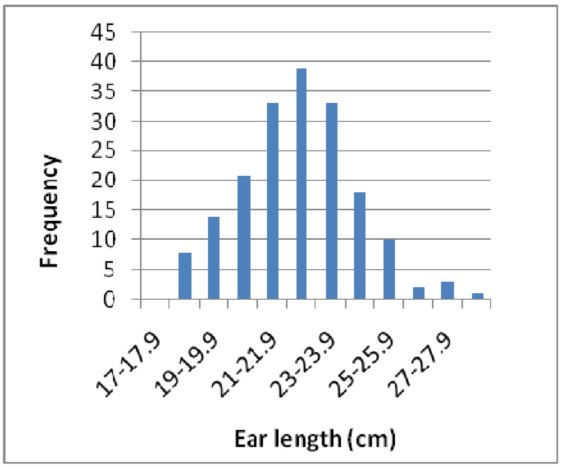

Figure 4.5: Ear length of hybrids at site A

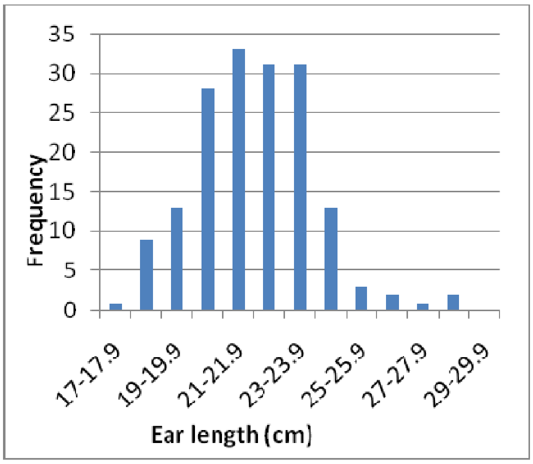

Figure 4.6: Ear length of hybrids at site B

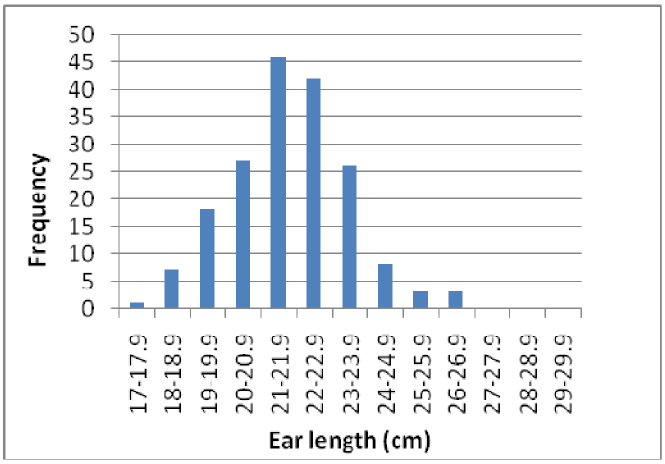

Figure 4.7: Ear length of hybrids at site C

Figure 4.8 and 4.9 show the highest ear weight at Makhathini which was between 200 and 299 kg, while at Dundee it was between 300 and 399 kg. There was at least a 100kg difference between the two sites with regards to ear weight. The distribution at the two sites was normal and continuous.

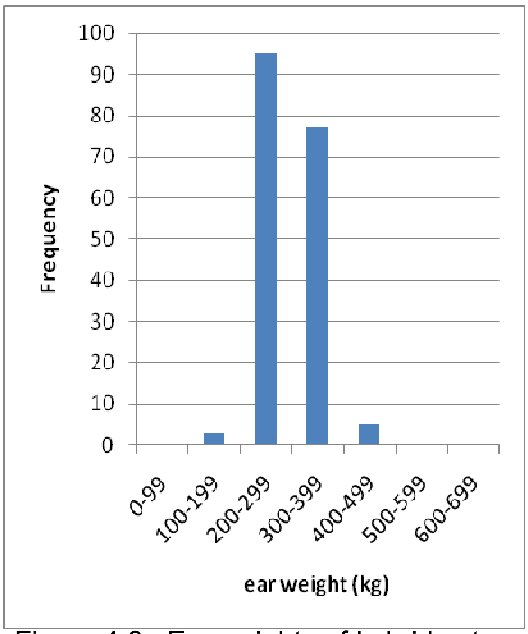

Figure 4.8: Ear weights of hybrids at site A

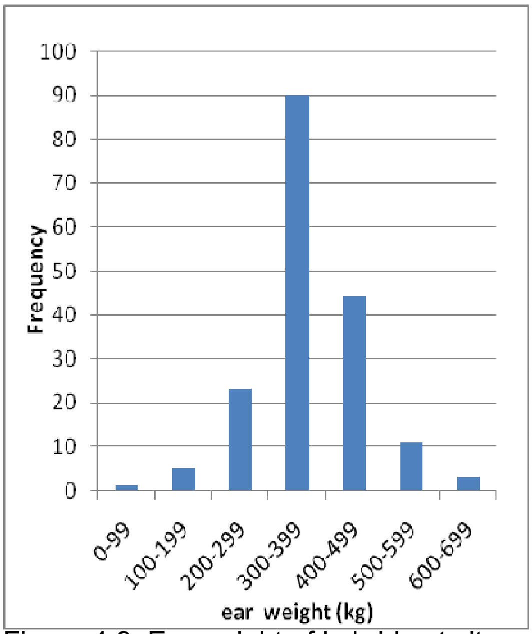

Figure 4.9: Ear weight of hybrids at site B

Figure 4.10 and Figure 4.11 shows that at least 50% of the plants in the plot had one ear at Makhathini, while 63% of the plants had one ear at Dundee. The distribution at the two sites was normal and continuous.

Marketability index

Hybrids had higher marketing ability indices at Dundee than Makhathini. The range for marketing ability of hybrids at Makhathini was between 4 and 12 while at Dundee it was between 2 and 14 (Figure 4.8 and 4.9). The frequency distribution of the hybrids at both sites was continuous and almost normal.

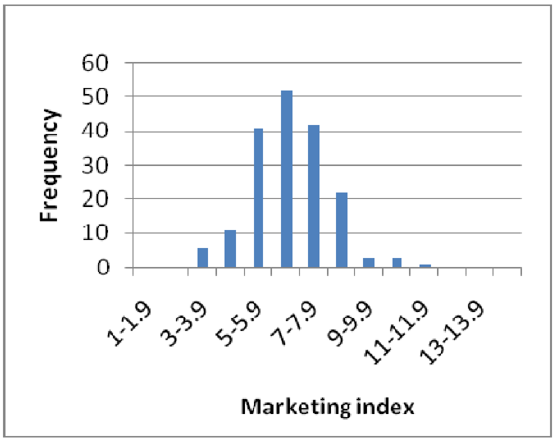

Figure 4.10: Marketing indexes of hybrids at site A

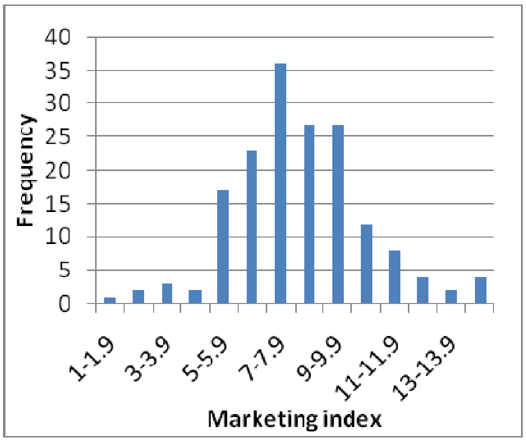

Figure 4.11: Marketing index of hybrids at site B

4.10 Frequency distribution of hybrids for agronomic traits

Flowering dates

There was almost a difference of a week in flowering of the hybrids at all sites Flowering of hybrids was earliest at Makhathini (65 days), Dundee (70 days) and latest at Cedara (85 days) (Figures 4.12, 4.13 and 4.14). Within each environment hybrids flowered within a week. The frequency distribution of hybrids was almost normal and continuous.

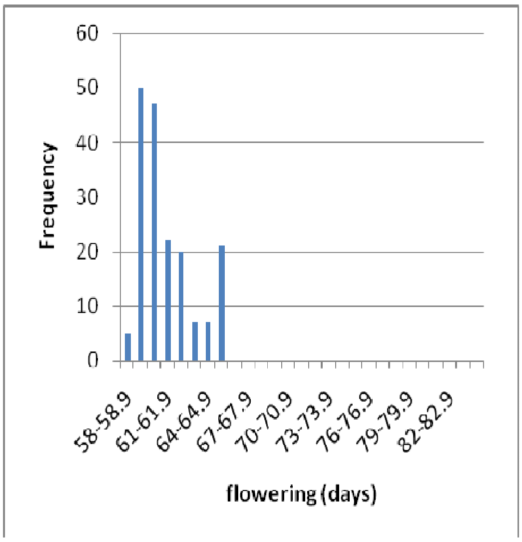

Figure 4.12: Flowering days of hybrids at site A

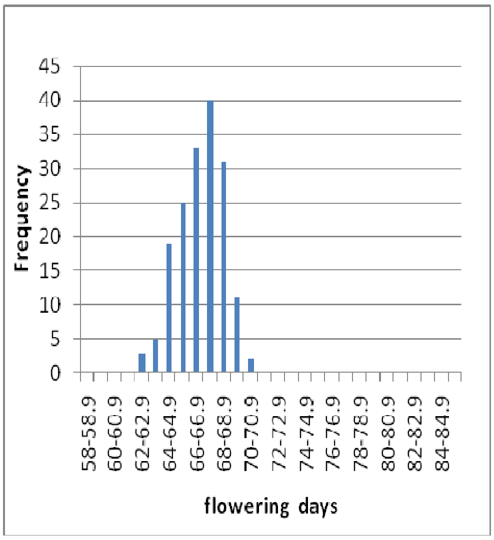

Figure 4.13: Flowering days of hybrids at site B

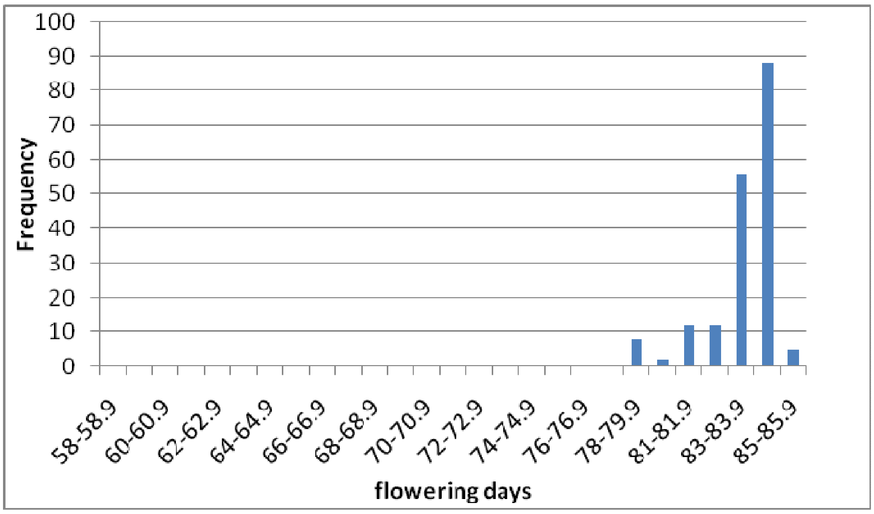

Figure 4.14: Flowering days of hybrids at site C

Plant height

Figure 4.15 and 4.16 show that the mean plant height for hybrids was 240cm at Makhathini and 300cm at Dundee, showing that the height of the hybrids increased by 60cm when planted at Dundee which is at higher elevation. The distribution at all the three sites was normal and continuous.

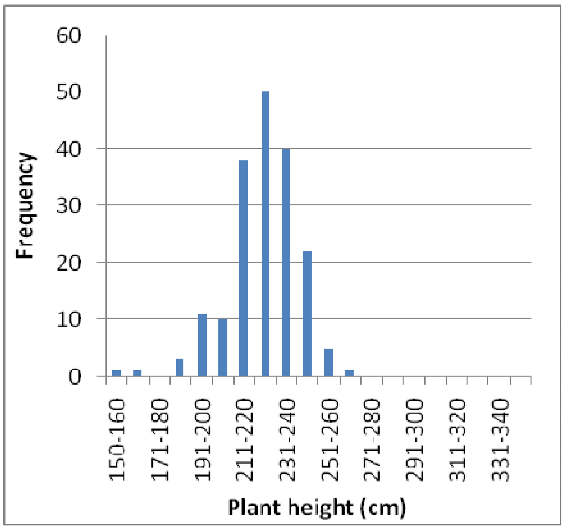

Figure 4.15: Plant heights of hybrids at site A

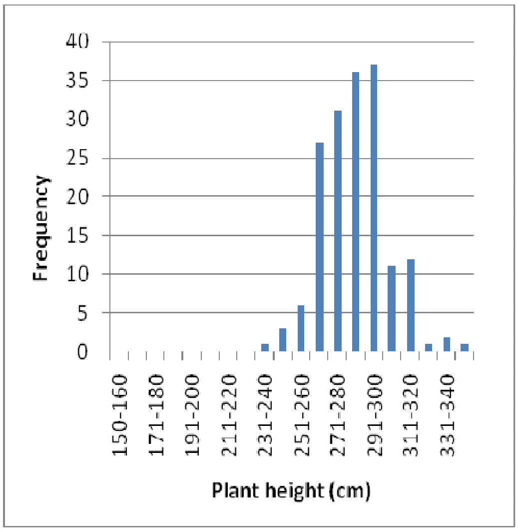

Figure 4.16: Plant height of hybrids at site B

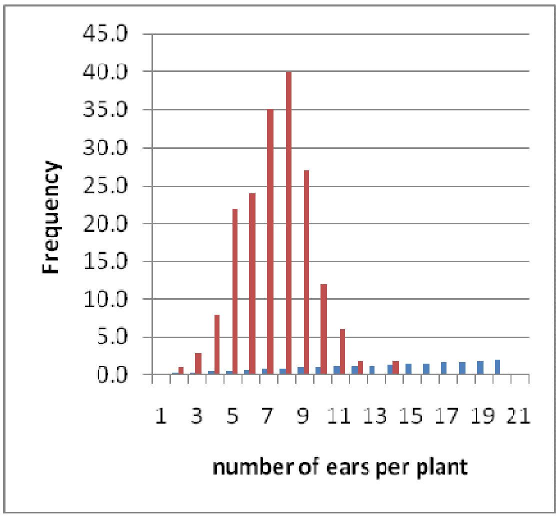

Figure 4.17: Number of ears per hybrid at site A

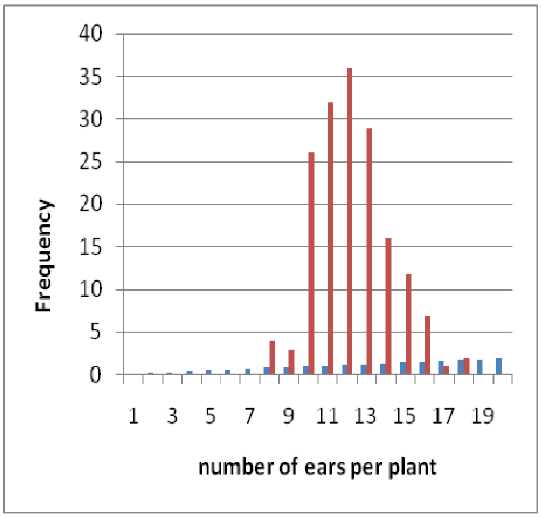

Figure 4.18: Number of ears per hybrid at site B

4.11 Discussion

Genotype x environment interaction effects

The hybrid x site interaction effects were highly significant for all the traits except marketability index indicating that hybrids displayed different levels of stability for ear yield, ear length and single ear weight but they exhibited stable performance for marketability. Some hybrids were adapted to the lowland conditions at Makhathini, for example the control hybrid SC701 performed dismally at Makhathini but was in the top 10 performing hybrids at Dundee. Even the testers showed differences in their performance, the PA1 showed low adaptation at Makhathini but it performed better at Dundee. However, PA1 showed good GCA for Ear Weight. Generally, P1 had good means in all green maize traits.

Cedara was the highest grain yielding environment compared to Dundee and Makhathini. The geographical information (Appendix 1) indicates that Cedara temperatures favor the growth of maize in summer, while Makhathini temperatures favored the growth of maize only in winter. High temperature has been reported by Pingali and Pandey (2001) as one of the maize production constraints. Therefore, the results in this study confirm that high temperature is a constraint to maize production because it affects yield and other related traits. The majority of the hybrids had long ears at Makhathini (24 cm) and Dundee (24 cm) while at Cedara most hybrids were 22 cm. From this, one can assume that Makhathini yielded better than Cedara, but it was not. This results show that grain filling was more affected by heat stress than ear length. Ideally grain-filling period of maize should be as long as practically possible to allow maximum production and storage of dry matter.

The Site X Line interaction effects were significant for all the green maize traits except Single Ear Weight suggesting that the GCA effects which are attributable to the lines were interacting with the environments. A similar observation was made for the GCA for testers which also showed significant interaction with the environments for all traits. Overall the results suggested that different hybrids should be developed for the different environments that are represented by the three sites. Therefore the promising hybrids will be evaluated at many locations to identify the ones that are specifically adapted to the target environments.

Combining ability and gene effects for green maize traits

The hybrids were highly significantly different for grain yield at Makhathini, Cedara and Dundee which indicated the opportunity to select hybrids that are suitable for the different environments. Variation among hybrids for all green maize traits could be explained by the significant GCA effects for the lines and GA for the testers; because both the line and testers main effects, respectively, were highly significant for all the traits. This suggested that genes with additive effects were important for controlling ear yield, single ear weight, ear length and the marketability index. The Line x Tester interaction effects were significant for all the green maize traits except Ear Length, indicating that SCA effects were also controlling the ear yield, single ear yield and marketing index. This observation also supported that the non-additive gene effects were significant for conditioning these traits. Although the literature does not show any data for green maize traits, previously, Unayi et al. (2004) reported that both GCA and SCA effects of genotypes were significantly different for grain yields which agree with findings from the current study.

The maize inbred lines, such as GML34, GML95, GML68 and GML105. GML94, GML93 and GML99, that exhibited good general combining ability for all the green maize traits, will be advanced in the breeding programme because of their potential utility in making hybrids. Whereas some of the lines displayed good GCA for one, two or three of the four green maize traits – such lines will be improved for those traits because they were performing below the mean. Examples include GML18 and GML85, GML98, GML38 and GML100, GML75, GML102 and GML103. Notably the nine lines that displayed good GCA for marketability index across the sites will be considered for breeding hybrids that are adapted to all the three target environments. Presumably these lines carry the genes for adaptation which others lacked because most of the hybrids showed no broad adaptation. In a practical plant breeding programme the 12 lines that showed negative GCA in crosses with the testers P1 and PA1 will be discarded. However, only two testers were used to discriminate the lines and were probably not complementary with these lines suggesting that other testers can be considered for green maize hybrids.

Unfortunately combining ability of maize lines for green maize traits has been scarcely reported in the literature which limits the scope of selection for potential testers for green maize hybrids. The current study therefore provided the starting point for the development of specialty hybrids for green maize.

Only the best seven hybrids exhibited significant positive SCA effects for marketing index which is desired. This can be attributed to some non additive gene effects because epistasis has been scarcely reported in maize for the yield related traits. The bottom five hybrids also had significant negative SCA effects for the same trait suggesting that there could also be some genes for non additive in the undesired direction. A similar trend was observed for ear yield. Almost all the bottom 10 hybrids displayed negative or neutral SCA effects for ear yield. None of the top 15 hybrids had significant SCA for ear length indicating that this trait was mainly under the influence of genes with additive effects.

Best hybrids selected for green maize potential

The following hybrids were selected for Ear Yield, Ear Weight and Marketability Index across three sites: GMH129, GMH126 and GMH 146 and GMH171. These hybrids will be evaluated in multi-location trials with potential for release as speciality green maize hybrids. The other hybrids such as GMH105, GMH172 and GMH149 were selected for Ear Weight and Marketability index across three sites would be subjected to further improvement. The hybrid GMH124 displayed the same top rank position for both Ear Yield and Ear Weight would require improvement for marketability index by improving the ear length and single ear weight. Hybrids GMH181, GMH147 and GMH112 were selected for Ear Yield trait across the sites indicating their potential for use as grain hybrids. The three hybrids selected for Ear Length traits, such as GMH167, GMH133 and GMH102, require improvement for the other three traits. The inbreds of these hybrids would be subjected to further improvement of the traits that are lacking in their hybrids; this can be done in a backcross program.

Frequency distribution of the hybrids

At all the three sites a continuous distribution of the hybrids was observed for ear yield, ear length and marketability index. This observation indicates that the traits were controlled by many genes. This also confirms significance of additive effects as reflected by GCA effects. Green maize traits can therefore be improved through accumulation of minor favorable alleles with additive effects. These genes can be fixed in the lines through self pollination, and the significant non-additive variation that was observed can be exploited by making hybrids between complementary inbred lines. These included the top 15 hybrids which involved the tester P1 and only one involve PA1 which confirms superiority of P1 over PA1, especially at Cedara. This can be explained by the fact that Cedara is the disease-prone environment and P1 is resistant to most foliar diseases including Grey Leaf Sport (GLS). The PA1 is susceptible to foliar diseases especially GLS, hence it might have conferred susceptibility to its progenies. On the other hand results in Table 4.21 show that hybrids containing PA1 were among the best and dominated the top 5 positions at Dundee. The reason is that there were no foliar disease infections at Dundee.

At Makhathini, hybrids involving P1 were in the top 15 for ear yield. However, one hybrid involving PA1 (GMH91) was ranked as the best and two other PA1 test crosses were among the top 15 (Table 4.23). This can be explained by the fact that P1 is tolerant to abiotic stress; while PA1 is susceptible hence it performs poorly under abiotic stress conditions at Makhathini. However, for dry grain yield most of the hybrids in the top 10, except one, were P1 progenies because P1 is tolerant to abiotic stress, while PA1 is susceptible. At Cedara the line GML94 combined very well with both testers and it appeared in the top 15, indicating that it is a good general combiner and can be used to make good hybrids with both testers.

All the top 15 hybrids at least exhibited prolificacy across the sites, providing the opportunity of selection for the best ears which are suitable for the green maize market. Serna-Saldivar (2000) indicated that maize for fresh consumption should have a higher number of usable ears.

Relationships among the traits

Ear yield of the hybrids was positively correlated with plant height, and number of ears per plant, indicating that ear yield can be improved indirectly when breeders select for tall plants, and prolificacy in the hybrids. This observation is consistent with previous reports by Hallauer and Miranda (1988). Ear length was positively and highly significantly correlated to grain yield suggesting that yield can be enhanced by improving the size of the ears. Hallauer and Miranda (1988) also reported a positive relationship between yield and ear length. Marketability was positive and significantly correlated with grain yield, plant height and number of ears per plant. Marketability was negative and significantly correlated with anthesis date and ear position suggesting that hybrids with superior marketing traits also had low ear position and flowered early in these environments. The low ear placement would be desired to reduce the incidence of stem and stalk lodging which are associated with high ear placement in maize.

4.12 Conclusion and Recommendations

The first of objective was to determine the combining ability of advanced inbred maize lines for ear yield, ear length, single ear weight and marketing ability index and desired agronomic traits. Results indicated that both GCA and SCA effects were important for marketing ability, fresh yield and grain yield. These findings suggest that genes with both additive and non-additive effects, respectively, were important in controlling these traits in testcross hybrids. The maize inbred lines, such as GML34, GML95, GML68 and GML105. GML94, GML93 and GML99, which exhibited good general combining ability for all the green maize traits, will be advanced in the breeding programme because of their potential utility in making green maize specialty hybrids.

The second objective was to identify new hybrids with potential for green maize production in different environmental niches in KwaZulu-Natal, in South Africa. Experimental hybrids with outstanding performance were identified, and would be advanced in the breeding programme. The following hybrids were selected for good Ear Yield, Ear Weight and Marketability Index across three sites: GMH129, GMH126 and GMH 146 and GMH171. These hybrids will be evaluated in multi-location trials with potential for development into speciality green maize hybrids for both the lowland and mid-altitude environments that are represented by the three sites.

The study also aimed at determining the relationships between marketability, which is the aggregate of the major green maize traits, and the desired agronomic traits. The study revealed that marketability was positively and highly significantly associated with grain yield, plant height and number of ears per plant, but it was negatively and high significantly correlated with anthesis date. The relationship between the green maize marketability indices with agronomic traits has never been reported in the literature. Nonetheless the relationships between grain yield and other agronomic traits are consistent with previous findings in the literature.

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5 General Research Overview

5.1 Introduction

This chapter provides an overview of green maize production, breeding implications of green maize hybrids development and its challenges, recommendations and future direction in green maize development.

5.2 Research objectives

The objectives of the research were as follows:

a) To determine the ideal quality traits required by consumers (end-user traits) for fresh maize hybrids;
b) To determine agronomic requirements for green maize hybrids,
c) To determine production constraints, production trends and economics of green maize production at Mjindi and Ndumo irrigation schemes in KwaZulu-Natal, South Africa,
d) To determine the combining ability of 95 advanced inbred lines for green maize properties and desired agronomic traits.

5.3 Summary of the Main Findings

Both GCA and SCA effects were found to be important for marketability, fresh yield and grain yield indicating that both, additive and non-additive effects, respectively, were important in conferring the green maize traits in hybrids.

The desired green maize model as described by farmers should have the following characteristics, for agronomic traits and market traits:
1) high grain yield 2) medium ear placement, 3) medium plant height 4) short growing period, 5) flint grain texture, 6) white grain color, 7) fat and long cobs, 8) non-popping during roasting (high roasting quality) and long shelf life.

There is potential in green maize business especially in the Irrigation Schemes. However, lack of hybrids that are suitable for green maize production is still a challenge to green maize producers. The annual return per hectare was R21,109 which translated to total returns of about R300, 000 per household over two reasons per year. This indeed, is an indicator of a good enterprise, which is reflected by the ownership of assets by farmers.

Potential hybrids for green maize production have been identified. The hybrids were highly significantly different for ear yield and marketability indices and for most of the agronomic traits at all sites. Marketability was positively and highly significantly correlated with grain yield, plant height and number of ears per plant, but it was negatively and significantly correlated with anthesis date. These hybrids exhibited better yield over the widely grown hybrid SC701 across the three sites as follows: at Dundee 3-10% (Appendix 3) Cedara 35-59% (Appendix 4) and Makhathini 11-100% (Appendix 5). Further testing of these hybrids at many other sites would be recommended.

Breeding progress can be compromised by the observation of the genotype x environmental interaction effects (GXE). Consequently different sets of hybrids appeared in the top 15 at each site. Only a few hybrids exhibited high performance consistently in at least two mega environments.

5.4 Breeding implications for green maize hybrids and its challenges

The study has the following implications for breeding specialty green maize hybrids in KwaZulu-Natal in South Africa:

The survey study demonstrated that participation of farmers, breeders and consumers in variety development will result in a green maize hybrid model with the preferred traits. When developed into tangible products, such hybrids would be easily adopted by the farmers who are producing green maize in this agricultural ecosystem with positive impact on productivity. Hybrids with potential for green maize production were identified and will be improved for the preferred traits.

Due to high genetic variation displayed by the hybrids in different sites, breeders therefore need to increase the number of testers and do crosses with the selected parents of the top 45 hybrids to identify stable hybrids for green maize production. Testers that have attributes described by farmers can be obtained from the germplasm database.

There are challenges in breeding green maize hybrids, such as lack of green maize standard checks especially for summer production, lack of literature on green maize shelf life and taste measurements. Another challenge is the economic view aspect of green maize business

The study indicated that there is potential in green maize business. However the size of the market and its distribution is not yet defined, giving opportunity for other studies about the whole value chain for green maize production.

5.5 Future directions

The following recommendations could be made:

a) Parents of the top 45 hybrids (15 from each environment) selected should be further crossed to at least 4 more testers to expand the number of potential hybrids, which will then be tested in the whole green maize producing areas of Kwa-Zulu Natal. Such areas include Tugela ferry, Camperdown and Vryheid.
b) Market study is recommended to give information on market size, market distribution and market trend. This will give total tons of green maize produced and sold in KZN.
c) Consumer sciences study is also recommended, to provide information on green maize nutrient content and shelf life.
d) Green maize hybrid with high vitamin A content is also recommended. Consumer preference for this maize has not been quantified, given its nutritional superiority to white maize.

Participation of the farmers and consumers in all said studies should be considered for the adoption of the hybrid.

6 Appendices

Appendix 1: Geographical information for Research stations

Station Name	Latitude	Longitude	Altitude
MAKATINI	-27.39^{0}S	32.17^{0}E	77m

Maximum Temperatures [°C]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	34.06	35.29	34.06	30.54	29.56	26.07	26.71	29.00	30.08	28.69	30.22	31.45	30.48
2008	33.07	34.62	32.53	29.37	28.69	25.92	27.40	28.72	28.71	30.20	30.67	33.21	30.26
2009	33.55	32.26	32.06	30.79	28.48	27.34	26.20	26.49	28.61	27.33	28.07	31.45	29.20
AVERAGE	33.27	34.13	32.59	30.28	28.66	26.49	27.15	27.22	29.08	29.22	30.50	31.66	

Minimum Temperatures [°C]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	20.96	21.55	19.62	16.64	10.95	10.87	8.83	11.38	16.58	17.40	19.11	19.63	16.13
2008	21.32	20.04	20.05	16.21	14.00	11.80	10.11	13.79	13.53	16.97	20.33	21.41	16.63
2009	22.32	21.22	19.21	16.28	14.53	12.23	8.06	11.99	14.98	18.30	17.78	19.63	16.08
AVERAGE	21.62	21.26	19.49	16.58	13.01	11.19	9.35	11.63	14.89	17.80	19.77	20.50	

Maximum Relative Humidity [%]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	93.03	93.16	92.66	95.53	94.45	95.96	94.49	91.31	91.58	91.35	91.20	92.41	93.09
2008	89.88	89.27	91.96	92.40	94.94	94.47	94.17	90.24	88.72	86.35	90.01	88.04	90.87
2009	90.25	92.77	92.70	91.40	93.72	91.36	93.56	93.22	89.96	92.36	92.11	92.41	92.13
AVERAGE	91.85	92.45	92.61	93.54	93.96	94.13	94.39	84.95	90.85	90.60	91.42	91.71	

Minimum Relative Humidity [%]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	39.24	37.45	34.81	45.38	27.67	41.78	29.52	27.51	37.75	44.13	47.22	44.88	38.11
2008	41.80	34.08	40.10	39.44	41.17	42.33	30.77	32.11	33.10	38.08	47.38	41.54	38.49
2009	45.63	47.85	42.35	36.36	39.96	33.70	30.32	37.30	39.27	53.06	51.50	44.88	41.57
AVERAGE	44.32	40.53	39.52	40.57	35.37	38.19	30.43	31.62	36.91	44.64	46.51	45.48	

RAINFALL [mm]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	95.80	47.90	23.60	59.40	0.00	50.60	5.90	0.00	14.80	49.90	93.10	96.50	537.50
2008	32.50	1.60	49.60	54.80	10.40	31.00	1.00	1.60	15.90	19.80	34.80	50.90	303.90
2009	54.40	87.30	13.10	11.50	52.50	5.50	3.50	53.10	5.20	46.80	3.10	96.5	336.00
AVERAGE	60.90	45.60	28.77	41.90	20.97	29.03	3.47	18.23	11.97	38.83	43.67	73.70	

Source of data: ARC

Station Name	Latitude	Longitude	Altitude
CEDARA_PP	29.54^{0}S	30.26^{0}E	1066m

1.1 Maximum Temperatures [°C]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	26.86	28.19	25.22	23.59	23.4	19.79	20.75	22.37	24.28	21.2	23.04	24.49	176.17
2008	26.57	26.61	25.06	22.23	23.2	19.39	21.15	22.93	22.79	22.8	24.33	26.25	176.25
2009	25.43	26.14	25.57	24.7	22.67	20.17	20.35	21.99	22.53	22.68	22.42	24.94	176.05
AVERAGE	26.29	26.98	25.28	23.51	*23.09*	*19.78*	*20.75*	*22.43*	*23.20*	22.23	23.26	25.23	

1.2 Minimum Temperatures [°C]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	15.45	15.67	13.88	11.75	6.03	3.52	2.64	5.37	10.88	11.37	12.78	13.64	163.84
2008	5.95	15.01	12.95	9.01	7.35	4.23	2.92	5.89	5.88	10.05	13.01	14.93	162.71
2009	14.85	15.23	13.33	9.84	6.75	3.72	1.31	4.9	7.67	11.24	11.55	13.66	163.31
AVERAGE	12.08	15.30	13.39	10.20	*6.71*	*3.82*	*2.29*	*5.39*	*8.14*	10.89	12.45	14.08	

1.3 Maximum Relative Humidity [%]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	93.97	94.57	93.26	92.77	79.13	82.73	79.52	81.48	89.3	92.94	94.37	93.2	236.48
2008	95.8	96.53	96.75	95.66	94.7	94.86	88.83	93.35	91.76	96.08	95.9	95.65	241.84
2009	96.36	95.93	96.05	95.54	94.74	93.65	89.63	91.15	93.64	95.55	94.49	95.52	241.63
AVERAGE	95.38	95.68	95.35	94.66	*89.52*	*90.41*	*85.99*	*88.66*	*91.57*	94.86	94.92	94.79	

Minimum Relative Humidity [%]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	48.74	42.93	46.65	45.13	24.23	29.53	23.9	28.72	40.57	50.74	56.67	60.56	192.72
2008	39.74	51.21	48.89	44.14	34.43	38.52	38.52	28.99	30.47	51.65	54.61	52.33	193.96
2009	59.23	54.45	48.82	41.34	36.32	32.23	22.81	29.65	38.38	51.06	55.04	54.86	194.86
AVERAGE	49.24	49.53	48.12	43.54	*31.66*	*33.43*	*28.41*	*29.12*	*36.47*	51.15	55.44	55.92	

1.4 RAINFALL [mm]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	72.2	18.9	107.9	34.8	0.5	31.8	0	11	31.3	169	177.9	81.5	2743.8
2008	17.1	67.1	47.8	75.2	0.6	22.2	0	4.4	32.7	26.7	89.65	64.52	2455.97

2009	82.04	65.79	27.43	21.34	48.51	2.54	0.25	27.43	9.91	92.97	70.36	52.84	2510.41
AVERAGE	57.11	50.60	61.04	43.78	16.54	18.85	0.08	14.28	24.64	96.22	112.64	66.29	

Source of data ARC.

Station Name	Latitude	Longitude	Altitude
DUNDEE RES STATION	28.13^0 S	30.31^0E	1219m

1.1 Maximum Temperatures [°C]													
Year	Jan	Feb	Mar	Aprill	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	28.12	30.73	27.9	25.09	23.97	20.77	20.21	22.45	28.14	22.5	26.1	26.12	177.62
2008	26.97	27.9	25.65	22.95	23.1	20.37	21.31	24.24	25.71	26.72	27.59	28.61	177.62
2009	27.75	26.66	26.08	24.98	21.93	19.4	19.31	21.23	30.32	21.35	27.43	30.22	177.36
AVERAGE	27.61	28.43	26.54	24.34	23.00	20.18	20.28	22.64	28.06	23.52	27.04	28.32	
1.2 Minimum Temperatures [°C]													
Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	14.95	14.97	13.63	10.43	2.85	2.94	0.94	4.94	9.88	11.55	13.12	13.85	163.16
2008	15.13	15.29	13.1	8.89	5.77	3.61	2.41	5.35	7.43	11.27	14.44	15.24	163.53
2009	15.85	15.56	13.49	9.24	6.63	4.12	-0.11	4.72	8.65	11.44	11.73	12.89	163.32
AVERAGE	15.31	15.27	13.41	9.52	5.08	3.56	1.08	5.00	8.65	11.42	13.10	13.99	
1.3 Maximum Relative Humidity [%]													
Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	98	98	98	97.55	95.8	97.06	95.56	96.69	95.48	98	97.89	98	244.08
2008	98	98	98	98	98	98	93	93	93.68	96.61	96.66	94.09	243.31
2009	94.48	94.96	95.16	94.73	89.98	87.75	90.48	90.52	81.7	96.02	95.41	94.47	239.59
AVERAGE	96.83	96.99	97.05	96.76	94.59	94.27	93.01	93.40	90.29	96.88	96.65	95.52	
Minimum Relative Humidity [%]													

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2007	48.09	39.62	40.69	45.79	22.97	33.64	28	30.08	30.23	59.27	52.11	52.29	191.52
2008	54.49	48.24	48.32	46.23	39.71	39.44	28.98	29.21	32.99	46.3	42.27	37.77	192.46
2009	45.3	46.36	40.03	31.81	31.08	31.34	19.99	27.3	9.65	53.81	37.5	35.08	186.02
AVERAGE	49.29	44.74	43.01	41.28	31.25	34.81	25.66	28.86	24.29	53.13	43.96	41.71	

1.4 RAINFALL [mm]

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	122.4	79.3	41.1	25.6	0.3	27.7	0.5	3.5	9	222.6	161.5	73.6	2774.10
2008	113.1	68.1	90.7	58.1	5.7	16	0.9	1.1	14.3	57.2	130.48	156.71	2720.39
2009	200.39	155.19	65.27	4.32	18.8	6.35	0.51	73.4	0	50.55	106.43	179.07	2869.28
AVERAGE	145.30	100.86	65.69	29.34	8.27	16.68	0.64	26.00	7.77	110.12	132.80	136.46	

Source of data ARC.

Appendix 2: Features of the experimental inbred lines derived from the population HYP16

Name	Pedigree	Origin	Plant	Ear	Ear \	Plant	Ear	Grain	Anth	Prolificacy
			height	Height	position	Aspect	Asp	Tex	Date	
GML1	HYP16-F3B-3-3-B-B-B	09MAK15-1	175	85.0	0.49	3.0	3.0	2.0	96.0	3
GML2	HYP16-F3B-6-1-B-B-B	09MAK15-2	190	85.0	0.45	3.0	1.0	5.0	96.0	3
GML3	HYP16-F3B-7-1-B-B-B	09MAK15-3	183	60.0	0.33	4.0	5.0	5.0	90.0	3
GML4	HYP16-F3B-7-2-B-B-B	09MAK15-4	170	83.0	0.49	4.0	4.0	2.0	90.0	3
GML5	HYP16-F3B-11-2-B-B-B	-09MAK15-5	188	96.0	0.51	4.0	2.0	4.0	96.0	3
GML6	HYP16-F3B-11-3-B-B-B	-09MAK15-6	161	91.0	0.57	3.0	2.0	2.0	96.0	2
GML7	HYP16-F3B-13-1-B-B-B	-09MAK15-7	150	75.0	0.50	3.0	2.0	3.0	96.0	2
GML8	HYP16-F3B-14-1-B-B-B	-09MAK15-8	175	86.0	0.49	3.0	3.0	3.0	94.0	3
GML9	HYP16-F3B-14-3-B-B-B	-09MAK15-9	152	84.0	0.55	3.0	2.0	1.0	94.0	3
GML10	HYP16-F3B-17-1-B-B-B	-09MAK15-10	150	86.0	0.57	3.0	2.0	1.0	94.0	2
GML11	HYP16-F3B-17-2-B-B-B	-09MAK15-11	170	83.0	0.49	4.0	2.0	2.0	96.0	2
GML12	HYP16-F3B-18-1-B-B-B	-09MAK15-12	150	79.0	0.53	4.0	3.0	2.0	96.0	2
GML13	HYP16-F3B-18-2-B-B-B	-09MAK15-13	172	80.0	0.47	3.0	4.0	2.0	100.0	2
GML14	HYP16-F3B-20-1-B-B-B	-09MAK15-14	155	76.0	0.49	4.0	3.0	3.0	96.0	3
GML15	HYP16-F3B-21-1-B-B-B	-09MAK15-15	150	80.0	0.53	4.0	3.0	3.0	96.0	2
GML16	HYP16-F3B-23-1-B-B-B	-09MAK15-16	179	85.0	0.47	4.0	4.0	2.0	96.0	2

Name	Pedigree	Origin	Plant height	Ear Height	Ear \ position	Plant Aspect	Ear Asp	Grain Tex	Anth Date	Prolificacy
GML17	HYP16-F3B-23-3-B-B-B	-09MAK15-17	192	104.0	0.54	3.0	2.0	4.0	96.0	2
GML18	HYP16-F3B-23-4-B-B-B	-09MAK15-18	175	75.0	0.43	3.0	3.0	2.0	96.0	2
GML19	HYP16-F3B-27-2-B-B-B	-09MAK15-19	175	76.0	0.43	4.0	4.0	3.0	96.0	3
GML20	HYP16-F3B-27-3-B-B-B	-09MAK15-20	158	86.0	0.54	3.0	4.0	3.0	94.0	3
GML21	HYP16-F3B-27-4-B-B-B	-09MAK15-21	195	102.0	0.52	4.0	3.0	4.0	96.0	3
GML22	HYP16-F3B-28-1-B-B-B	-09MAK15-22	154	61.0	0.40	4.0	4.0	3.0	94.0	2
GML23	HYP16-F3B-28-2-B-B-B	-09MAK15-23	173	108.0	0.62	4.0	4.0	4.0	96.0	2
GML24	HYP16-F3B-29-1-B-B-B	-09MAK15-24	196	82.0	0.42	3.0	3.0	3.0	104.0	2
GML25	HYP16-F3B-29-2-B-B-B	-09MAK15-25	180	98.0	0.54	3.0	3.0	4.0	96.0	2
GML26	HYP16-F3B-43-3-B-B-B	-09MAK15-26	101	50.0	0.50	3.0	4.0	2.0	96.0	2
GML27	HYP16-F3B-43-4-B-B-B	-09MAK15-27	162	71.0	0.44	3.0	3.0	4.0	96.0	2
GML28	HYP16-F3B-44-2-B-B-B	-09MAK15-28	162	70.0	0.43	3.0	3.0	1.0	96.0	3
GML29	HYP16-F3B-50-3-B-B-B	-09MAK15-29	171	80.0	0.47	4.0	3.0	5.0	90.0	2
GML30	HYP16-F3B-52-1-B-B-B	-09MAK15-30	188	93.0	0.49	4.0	4.0	2.0	96.0	2
GML31	HYP16-F3B-56-1-B-B-B	-09MAK15-31	145	69.0	0.48	3.0	3.0	3.0	96.0	2
GML32	HYP16-F3B-56-2-B-B-B	-09MAK15-32	188	79.0	0.42	4.0	3.0	2.0	96.0	3
GML33	HYP16-F3B-56-3-B-B-B	-09MAK15-33	200	87.0	0.44	3.0	2.0	3.0	96.0	3

Name	Pedigree	Origin	Plant height	Ear Height	Ear \ position	Plant Aspect	Ear Asp	Grain Tex	Anth Date	Prolificacy
GML34	HYP16-F3B-56-4-B-B-B	-09MAK15-34	200	85.0	0.43	3.0	3.0	4.0	96.0	3
GML35	HYP16-F3B-58-1-B-B-B	-09MAK15-35	153	65.0	0.42	3.0	4.0	3.0	96.0	3
GML36	HYP16-F3B-58-3-B-B-B	-09MAK15-36	125	65.0	0.52	4.0	0.0	1.0	96.0	3
GML37	HYP16-F3B-60-2-B-B-B	-09MAK15-37	176	86.0	0.49	3.0	3.0	2.0	90.0	3
GML38	HYP16-F3B-69-4-B-B-B	-09MAK15-38	206	95.0	0.46	3.0	3.0	3.0		3
GML39	HYP16-F3B-70-1-B-B-B	-09MAK15-39	154	76.0	0.49		0.0	0.0		
GML40	HYP16-F3B-71-1-B-B-B	-09MAK15-40	200	96.0	0.48	4.0	3.0	2.0	96.0	3
GML41	HYP16-F3B-76-1-B-B-B	-09MAK15-41	202	95.0	0.47	4.0	1.0	4.0	96.0	2
GML42	HYP16-F3B-77-1-B-B-B	-09MAK15-42	137	65.0	0.47	4.0	3.0	2.0	91.0	3
GML43	HYP16-F3B-79-1-B-B-B	-09MAK15-43	193	85.0	0.44	4.0	3.0	3.0	90.0	2
GML44	HYP16-F3B-79-2-B-B-B	-09MAK15-44	165	95.0	0.58	3.0	4.0	5.0	96.0	2
GML45	HYP16-F3B-83-1-B-B-B	-09MAK15-45	170	85.0	0.50	4.0	1.0	5.0	90.0	3
GML46	HYP16-F3B-83-2-B-B-B	-09MAK15-46	172	75.0	0.44	4.0	3.0	1.0	90.0	3
GML47	HYP16-F3B-85-1-B-B-B	-09MAK15-47	170	97.0	0.57	5.0	4.0	2.0	96.0	3
GML48	HYP16-F3B-86-1-B-B-B	-09MAK15-48	162	75.0	0.46	4.0	2.0	3.0	96.0	3
GML49	HYP16-F3B-86-2-B-B-B	-09MAK15-49	167	83.0	0.50	4.0	4.0	3.0	96.0	2
GML50	HYP16-F3B-87-1-B-B-B	-09MAK15-50	154	70.0	0.45	4.0	3.0	3.0	96.0	2

Name	Pedigree	Origin	Plant	Ear	Ear \	Plant	Ear	Grain	Anth	Prolificacy
			height	Height	position	Aspect	Asp	Tex	Date	
GML51	HYP16-F3B-91-1-B-B-B	-09MAK15-51	206	106.0	0.51	4.0	2.0	4.0	96.0	2
GML52	HYP16-F3B-91-2-B-B-B	-09MAK15-52	165	65.0	0.39	8.0	3.0	2.0	90.0	3
GML53	HYP16-F3B-92-2-B-B-B	-09MAK15-53	174	84.0	0.48	4.0	4.0	1.0	96.0	3
GML54	HYP16-F3B-93-1-B-B-B	-09MAK15-54	205	97.0	0.47	5.0	2.0	5.0	96.0	3
GML55	HYP16-F3B-94-1-B-B-B	-09MAK15-55	183	83.0	0.45	4.0	4.0	4.0	90.0	3
GML56	HYP16-F3B-98-1-B-B-B	-09MAK15-56	166	86.0	0.52	4.0	3.0	3.0	96.0	3
GML57	HYP16-F3B-98-3-B-B-B	-09MAK15-57	161	80.0	0.50	4.0	4.0	1.0	96.0	3
GML58	HYP16-F3B-99-1-B-B-B	-09MAK15-58	175	73.0	0.42	4.0	3.0	1.0	96.0	3
GML59	HYP16-F3B-100-2-B-B-B	-09MAK15-59	158	79.0	0.50	4.0	2.0	1.0	100.0	3
GML60	HYP16-F3B-100-3-B-B-B	-09MAK15-60	175	86.0	0.49	3.0	3.0	4.0	96.0	3
GML61	HYP16-F3B-102-1-B-B-B	-09MAK15-61	187	108.0	0.58	4.0	3.0	2.0	90.0	3
GML62	HYP16-F3B-102-2-B-B-B	-09MAK15-62	150	77.0	0.51	3.0	3.0	4.0	90.0	3
GML63	HYP16-F3B-102-4-B-B-B	-09MAK15-63	185	100.0	0.54	2.0	3.0	2.0	96.0	3
GML64	HYP16-F3B-119-1-B-B-B	-09MAK15-64	185	97.0	0.52	4.0	2.0	3.0	96.0	3
GML65	HYP16-F3B-119-2-B-B-B	-09MAK15-65	200	75.0	0.38	4.0	2.0	4.0	96.0	3
GML66	HYP16-F3B-124-1-B-B-B	-09MAK15-66	180	97.0	0.54	4.0	3.0	3.0	90.0	3
GML67	HYP16-F3B-127-1-B-B-B	-09MAK15-67	158	75.0	0.47	4.0	3.0	5.0	96.0	2

Name	Pedigree	Origin	Plant	Ear	Ear \	Plant	Ear	Grain	Anth	Prolificacy
			height	Height	position	Aspect	Asp	Tex	Date	
GML68	HYP16-F3B-128-1-B-B-B	-09MAK15-68	166	90.0	0.54	4.0	3.0	4.0	96.0	3
GML69	HYP16-F3B-133-1-B-B-B	-09MAK15-69	120	75.0	0.63	3.0	5.0	4.0	96.0	3
GML70	HYP16-F3B-136-2-B-B-B	-09MAK15-70	135	60.0	0.44	4.0	3.0	4.0	96.0	3
GML71	HYP16-F3B-146-1-B-B-B	-09MAK15-72	155	88.0	0.57	2.0	4.0	3.0	90.0	3
GML72	HYP16-F3B-146-2-B-B-B	-09MAK15-73	152	92.0	0.61	4.0	3.0	4.0	96.0	3
GML73	HYP16-F3B-147-1-B-B-B	-09MAK15-74	176	75.0	0.43	4.0	3.0	3.0	96.0	2
GML74	HYP16-F3B-148-1-B-B-B	-09MAK15-75	192	76.0	0.40	4.0	4.0	2.0	96.0	2
GML75	HYP16-F3B-151-2-B-B-B	-09MAK15-76	185	95.0	0.51	3.0	2.0	2.0	96.0	2
GML76	HYP16-F3B-157-1-B-B-B	-09MAK15-77	187	87.0	0.47	3.0	4.0	4.0	96.0	3
GML77	HYP16-F3B-166-1-B-B-B	-09MAK15-78	160	90.0	0.56	3.0	4.0	4.0	90.0	3
GML78	HYP16-F3B-167-1-B-B-B	-09MAK15-79	178	83.0	0.47	3.0	3.0	4.0	90.0	3
GML79	HYP16-F3B-168-1-B-B-B	-09MAK15-80	123	45.0	0.37	4.0	4.0	5.0	90.0	3
GML80	HYP16-F3B-171-2-B-B-B	-09MAK15-81	145	58.0	0.40	4.0	4.0	1.0	96.0	3
GML81	HYP16-F3B-172-1-B-B-B	-09MAK15-82	130	64.0	0.49	4.0	3.0	5.0	96.0	3
GML82	HYP16-F3B-175-1-B-B-B	-09MAK15-83	161	94.0	0.58	4.0	4.0	2.0	96.0	2
GML83	HYP16-F3B-175-2-B-B-B	-09MAK15-84	123	60.0	0.49	5.0	5.0	2.0	90.0	2
GML84	HYP16-F3B-179-2-B-B-B	-09MAK15-86	176	73.0	0.41	4.0	1.0	2.0	90.0	3

Name	Pedigree	Origin	Plant height	Ear Height	Ear \ position	Plant Aspect	Ear Asp	Grain Tex	Anth Date	Prolificacy
GML85	HYP16-F3B-183-1-B-B-B	-09MAK15-87	184	88.0	0.48	5.0	2.0	5.0	96.0	2
GML86	HYP16-F3B-186-1-B-B-B	-09MAK15-88	170	77.0	0.45	5.0	5.0	1.0	96.0	3
GML87	HYP16-F3B-191-1-B-B-B	-09MAK15-89	190	88.0	0.46	5.0	4.0	4.0	96.0	2
GML88	HYP16-F3B-193-1-B-B-B	-09MAK15-90	177	114.0	0.64	5.0	3.0	2.0	104.0	3
GML89	HYP16-F3B-211-2-B-B-B	-09MAK15-92	170	90.0	0.53	5.0	4.0	3.0	96.0	3
GML90	HYP16-F3B-212-2-B-B-B	-09MAK15-93	160	63.0	0.39	4.0	3.0	2.0	96.0	2
GML91	HYP16-F3B-218-1-B-B-B	-09MAK15-94	170	75.0	0.44	4.0	0.0	0.0	96.0	3
GML92	HYP16-F3B-218-2-B-B-B	-09MAK15-95	205	50.0	0.24	4.0	2.0	5.0	90.0	2
GML93	HYP16-F3B-221-1-B-B-B	-09MAK15-96	191	82.0	0.43	4.0	3.0	5.0	96.0	3
GML94	HYP16-F3B-222-2-B-B-B	-09MAK15-97	185	97.0	0.52	4.0	5.0	2.0	90.0	3
GML95	HYP16-F3B-227-1-B-B-B	-09MAK15-98	151	75.0	0.50	4.0	4.0	3.0	96.0	3
GML96	HYP16-F3B-234-1-B-B-B	-09MAK15-99	185	97.0	0.52	4.0	4.0	3.0	96.0	3
GML97	HYP16-F3B-235-1-B-B-B	-09MAK15-100	160	51.0	0.32	4.0	3.0	1.0	96.0	3
GML98	HYP16-F3B-235-2-B-B-B	-09MAK15-101	158	82.0	0.52	4.0	3.0	3.0	90.0	3
GML99	HYP16-F3B-236-1-B-B-B	-09MAK15-102	145	45.0	0.31	5.0	2.0	4.0	96.0	3
GML100	HYP16-F3B-236-2-B-B-B	-09MAK15-103	186	80.0	0.43	4.0	0.0	0.0	90.0	3
GML101	CML444-B	-09MAK15-106	152	70.0	0.46	3.0	3.0	3.0	96.0	3

Appendix 3: The top 15 hybrids means for green maize traits and agronomic traits at Dundee

HYBRIDS	Line	Tester	Ear Yield		Marketing ability		Ear Size		Ears No.	AD	SD	PH	EH	Ear Position	Text.	Grain Moisture (%)
			Mean (t/ha)	Relative to SC701 (%)	Mean Index	Relative SC701 (%)	Weight (g)	Length (cm)	#	days		cm			score	
GMH80	GML83	PA1	7.86	110	8.10	86	366.8	21.9	0.8	66.8	72.4	290.6	154.5	0.53	5	15.6
GMH4	GML4	PA1	7.77	108	7.27	77	347.7	21.0	1.1	64.9	69.5	282.7	144.1	0.51	5	20.7
GMH104	GML1	P1	7.76	108	9.19	97	403.0	22.3	1.2	68.0	70.7	280.2	153.2	0.54	3	20.2
GMH54	GML55	PA1	7.61	106	7.26	77	327.7	22.2	1.2	68.3	74.2	265.6	140.4	0.53	4	21.5
GMH138	GML44	P1	7.53	105	7.91	84	354.4	22.5	0.9	63.8	67.3	288.0	147.2	0.51	4	18.7
GMH47	GML48	PA1	7.49	105	3.88	41	191.6	20.5	1.2	69.1	70.3	298.2	190.4	0.63	4	19.0
GMH107	GML55	P1	7.36	103	9.88	105	423.8	23.1	1.5	67.2	70.8	305.3	166.9	0.55	4	17.8
GMH162	GML76	P1	7.36	103	8.92	95	377.5	23.3	1.6	66.7	69.4	309.6	150.4	0.49	3	21.3
GMH29	GML29	PA1	7.24	101	7.54	80	386.1	19.6	1.1	67.3	69.0	276.7	137.9	0.50	4	18.7
GMH152	GML65	P1	7.09	99	9.38	99	396.5	23.0	1.2	64.4	70.4	289.2	155.1	0.54	3	21.7
GMH180	GML99	P1	7.02	98	9.71	103	420.5	22.5	1.0	65.8	68.5	314.0	179.0	0.57	3	22.4
GMH66	GML68	PA1	6.92	97	7.45	79	316.5	23.3	1.0	67.4	76.5	296.2	151.5	0.51	4	20.2
GMH28	GML28	PA1	6.88	96	3.16	33	176.8	20.1	0.9	67.3	74.1	287.3	151.2	0.53	3	19.6
GMH7	GML76	PA1	6.88	96	6.09	64	275.8	21.0	1.1	69.0	76.2	275.5	147.2	0.52	4	21.8
GMH144	GML55	P1	6.79	95	10.06	107	419.6	24.0	1.4	66.0	69.7	276.5	139.8	0.50	4	21.3
Checks																
SC701			7.16	100	9.44	100	393.9	23.4	1.1	66.7	70.4	296.2	146.2	0.50	4	22.1
PAN6777			4.77		10.32	109	401.5	26.8	1.1	64.3	69.3	268.8	125.5	0.47	5	20.6

Grain texture, 1 = flint and 5 = dent; ear size (ear weight and ear length), ears number, anthesis date (AD), silking dates (SD), plant height (PH), ear height (EH), ear position (EPO), grain texture (TEX), and grain moisture

Appendix 4: The top 15 hybrid means for green maize and agronomic traits at Cedara

Hybrid Name	**Line**	**Tester**	**Ear Yield**		**Anthesis Date**	**Silking Date**	**Ear Length**	**Grain Texture**	**Grain Moisture content**
			Mean t/ha	**Relative to SC701 (%)**	days		cm	score	%
GMH120	GML20	P1	9.04	159	83.3	83.2	23.4	4	20.1
GMH115	GML15	P1	8.80	155	84.3	83.3	23.1	4	22.3
GMH155	GML68	P1	8.60	151	83.6	84.3	29.0	5	19.2
GMH146	GML57	P1	8.50	150	84.2	82.1	22.3	4	21.3
GMH145	GML56	P1	8.50	150	84.0	83.5	22.4	4	19.3
GMH159	GML73	P1	8.46	149	84.3	82.2	21.2	4	19.1
GMH91	GML94	PA1	8.30	146	84.3	81.4	21.0	5	20.6
GMH170	GML86	P1	8.27	146	83.7	83.3	22.1	4	20.2
GMH139	GML47	P1	8.16	144	81.8	79.8	23.9	4	18.6
GMH113	GML13	P1	8.08	142	84.0	81.3	24.2	3	20.3
GMH175	GML93	P1	7.97	140	83.8	79.6	21.6	4	19.7
GMH124	GML26	P1	7.76	137	84.3	81.2	23.1	4	22.2
GMH169	GML85	P1	7.70	136	84.2	82.1	22.2	5	19.4
GMH165	GML80	P1	7.68	135	84.3	84.3	21.5	4	20.8
GMH176	GML94	P1	7.66	135	83.9	84.4	22.4	4	21.2
Checks									
SC701			5.68	100	84.1	83.9	24.0	5	20.6
PAN6777			4.97	88	84.1	84.3	23.7	5	20.6

Grain texture, 1 = flint and 5 = dent

Appendix 5: The top 15 hybrids means for fresh ear yield, marketing ability, ear length and ear weight at Makhathini

Hybrid	**Line**	**Tester**	**Ear Yield**		**Marketing ability**		**Ear Length**	**Ear Weight**
			Mean t/ha	**Relative SC701 (%)**	**Mean index**	**Relative SC701 (%)**	**CM**	**(g)**
GMH91	GML94	PA1	13.3	238	6.78	83	22.7	296.7
GMH152	GML65	P1	12.1	217	7.61	93	22.8	335.9
GMH143	GML52	P1	11.9	213	7.78	95	21.4	363.9
GMH155	GML68	P1	11.7	211	8.91	109	23.4	377.2
GMH120	GML20	P1	11.6	208	8.64	105	25.6	333.2
GMH161	GML75	P1	11.2	202	6.57	80	20.4	319.1
GMH113	GML13	P1	11.2	202	7.48	91	25.1	296.9
GMH112	GML12	P1	11.1	200	7.27	89	23.3	309.9
GMH126	GML28	P1	10.9	196	8.41	103	23.9	350.7
GMH58	GML59	PA1	10.8	194	10.80	132	22.7	467.5
GMH167	GML82	P1	10.7	193	7.88	96	24.9	311.2
GMH178	GML97	P1	10.7	192	8.23	101	23.5	352.3
GMH148	GML59	P1	10.6	191	7.92	97	25.6	305.3
GMH115	GML15	P1	10.6	191	8.00	98	26.9	296.9
GMH90	GML93	PA1	10.5	189	6.74	82	22.1	306.3
Checks								
SC701			5.6	100	8.19	100	25.0	328.2
PAN7M07			4.1	74	7.54	92	25.3	299.6
PAN6777			10.5	189	8.62	105	24.7	351.3

Appendix 6: The top 15 hybrids means for green maize and agronomic traits at Makhathini

Hybrid Name	LINE	TESTER	Ear Yield		Anthesis Date	Silking Date	Ear Weight	Ear number	Ear Height	Ear Position	Plant height	Grain Moisture
			Mean t/ha	**Relative to SC701 (%)**	days		g		cm			(%)
GMH126	GML28	P1	6.03	372	59.3	64.4	209.8	0.9	97.4	0.43	226.0	18.4
GMH181	GML100	P1	5.32	328	59.6	64.9	180.3	0.9	111.2	0.43	252.1	16.9
GMH129	GML33	P1	5.29	326	59.8	64.8	228.9	1.0	110.4	0.52	216.6	18.8
GMH146	GML57	P1	5.23	323	59.2	64.5	131.5	1.1	111.1	0.51	215.5	23.6
GMH177	GML95	P1	5.12	316	60.0	64.7	127.9	1.2	106.1	0.46	231.8	20.6
GMH147	GML58	P1	5.10	315	61.0	66.0	211.9	0.9	94.1	0.45	217.3	18.8
GMH112	GML12	P1	4.88	301	62.9	65.3	178.3	0.8	112.8	0.48	233.1	17.3
GMH133	GML38	P1	4.86	300	60.2	65.2	164.2	0.9	117.5	0.58	200.9	14.3
GMH167	GML82	P1	4.81	297	61.2	65.9	154.9	0.9	123.5	0.52	237.4	17.6
GMH155	GML68	P1	4.80	297	59.5	64.3	129.1	0.9	105.6	0.42	247.7	17.6
GMH113	GML13	P1	4.72	292	59.8	64.8	157.9	0.9	103.3	0.43	238.9	18.8
GMH180	GML99	P1	4.70	290	65.3	70.0	221.1	0.7	107.0	0.50	215.4	15.9
GMH115	GML15	P1	4.56	281	60.5	65.4	175.8	1.0	113.1	0.49	230.2	17.4
GMH88	GML91	PA1	4.53	279	61.9	64.9	185.2	0.9	115.6	0.46	249.2	17.4
GMH171	GML89	P1	4.50	278	60.4	65.1	148.4	0.7	95.9	0.42	226.6	11.9
Checks												
PAN6777			4.07	251.	62.3	67.0	129.0	1.0	107.3	0.46	230.4	16.3
SC701			1.62	100	60.6	65.6	148.7	0.5	105.0	0.44	236.6	11.3