GENOTYPE BY ENVIRONMENT INTERACTIONS FOR SUCROSE CONTENT IN SUGARCANE *(Saccharum spp. hybrid)* CLONES GROWN UNDER RAINFED CONDITIONS IN WESTERN KENYA

BY

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DECLARATION BY CANDIDATE

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DEDICATION

This thesis is dedicated to my wife Kathrine and my children Oliver, Wyne, Sacchyll and Sharleen for their support, understanding, patience and encouragement. I also dedicate this thesis to my mother Violet Oweya and my late father Sammy Shikanda for their contribution and great interest in my education.

ABSTRACT

Sugarcane (*Saccharum spp hybrid*) refers to sucrose storing members of the family *(poaceae)* and is cultivated primarily for the extraction of sucrose (sugar) from the plant stalks. Recent uses of this tropical crop include the utilization of its plant biomass for cogeneration and production of ethanol. Genotype × Environment interaction is the relative difference in response of genotypes in different environments. Limited research has been conducted to determine the magnitude of G×E on sucrose content in Kenya. The objectives of this study were: (i) to avail and enhance information on the magnitude of genotype × environment interaction for sugarcane sucrose content, (ii) to evaluate 22 sugarcane clones and 3 cultivars for sucrose content and agronomic traits in Western Kenya, (iii) to identify promising clones of sugarcane for further testing. The study was conducted in three sites namely KALRO Sugar research Institute at Kibos, Mumias Sugar Company nucleus estate and South Nyanza Sugar Company Awendo in Western Kenya. Lattice square design with three replications was used in the study. Significant differences among the genotypes were observed in most traits tested; Genotype × location interactions were significant ($p \leq 0.01$) for milleable stalks, stalk girth, and brix. The effect of environment was significant for all the quantitative and qualitative traits studied. Milleable stalks and stalk height were significantly associated with cane yield. Significant correlations were observed among cane yield components with the exception of girth. Sucrose content was positively correlated with juice purity. Performance of clones in cane and sugar yield related traits varied across locations. Overall, the genotypes performed better in South Nyanza than in Kibos and Mumias in quantitative traits. However, performance was better in Kibos for qualitative traits. The most outstanding genotypes in both cane quality and yield were KEN 04 -1809, KEN 04 -1603, KEN 04-1079, KEN 04-419, KEN 04-2010 and KEN 04-2192. Genotype KEN 82-493 was outstanding in sucrose production across the three locations. This study has demonstrated the importance of multi-location testing of genotypes to enhance selection traits of interest.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	-	Agro-ecological zone
AFA	-	Agriculture and food authority
AMMI	-	Additive main multiplicative interactions
ANOVA	-	Analysis of Variance
Brix	-	Total soluble solids in a solution containing sugars
CCS	-	Commercial Cane Sugar
CTU	-	Cane testing Units
EAC	-	East African Community
FAO	-	Food and Agriculture Organization
GEI	-	Genotype Environment Interaction
Ha	-	Hectare
K	-	Potassium
KALRO	-	Kenya Agricultural and Livestock Research Organization
KESREF	-	Kenya Sugar Research Foundation
KSB	-	Kenya Sugar Board
LM 1	-	Lower midland 1
LM 2	-	Lower midland 2
METs	-	Multi environment trials
MSC	-	Mumias Sugar Company
N	-	Nitrogen
P	-	Phosphate
PCA	-	Principal component analysis
REML	-	Restricted maximum likelihood

SASRI	-	South Africa Sugar Research Institute
SBC	-	Sugarcane breeding centre
SONY	-	South Nyanza Sugar Company
SRI	-	Sugar Research Institute
TCH	-	Tonnes of cane per Ha
TSH	-	Tonnes of sugar per Ha.

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To God be all glory and honour

CHAPTER ONE

INTRODUCTION

1.1 Background information

1.1.1 The Kenya sugar industry

Sugarcane (*Saccharum spp*. *hybrid*) a taxa represented by stout, jointed, fibrous stalk of 2-6 m with sugar is a tall perennial grass of the genus *Saccharum* of family *Poaceae* (Clark *et al.,* 1995). It is native to warm temperate to tropical regions of South and Southeast Asia all having humid climate.

Sugarcane cultivation in Kenya begun in the early 19th Century by the Indian settlers in Kibos area (Luckman, 1959).The establishment of two factories Miwani in Kisumu and Ramisi in Kwale counties in 1923 marked the beginning of large-scale commercial sugarcane production in the country. To date eleven sugar mills namely Muhoroni, Chemelil, Mumias, Nzoia, South Nyanza Awendo, West Kenya, Soin, Kibos, Butali, Transmara, Sukari, and Kwale are operational (Jamoza, 2005; 2011). Two additional sugar companies are the upcoming in Rangwe and Dominion farms in Homabay and Siaya Counties respectively.

1.1.2 Economic importance of sugar cane farming.

Sugarcane is one of the major cash crops grown extensively all over in the world from tropical to sub-tropical regions. The plant is considered as one of the best converters of solar energy into biomass and sugar. It is a rich source of food (sucrose, jaggery and syrup), fibre (cellulose), fodder (green leaves and tops of cane plant, bagasse, and molasses and to some extent press mud), fuel and chemical. The main by-products are bagasse, molasses and press mud. The other products and their by-products of less commercial value are green leaves and tops, trash, boiler ash and effluent generated by sugar industry and distillery. Brazil is the largest sugar producer in the world followed by India (FAO Database, 2013). In Kenya sugarcane is ranked as the fourth major cash crop after tea (*Camellia sinensis* L.), horticultural crops, and Coffee (*Coffea arabica*).

The sugar industry plays an important role in the national economic development as it generates about Ksh 12 billion annually, supports directly and indirectly about 294,000 small and large scale farmers in Western Kenya. Approximately 8 million Kenyans derive their livelihood from sugarcane production. Current production stands at 632,000 metric tonnes of sugar annually milled from 5.81 million tonnes of sugarcane grown on 211,324 ha (AFA, SD 2015). The industry contributes about 7.5% of the country's GDP and has a major impact on economies of western Kenya and Nyanza regions and to a lesser extent Rift valley. This crop is expected to have a major impact on economic of coast region with the commissioning of Kwale International Sugar Company.(Kenya sugar industry strategic plan 2010-2014).

Domestic sugar production saves the country in excess of Kshs 20 billion, annually in foreign exchange and contributes to tax revenues to the exchequer). In the sugar belt zones the industry contributes to infrastructure development through road construction and maintenance, construction of bridges and social amenities such as health and recreation facilities. By far the largest contribution of the industry is its silent contribution to the fabric of communities and rural economies in the sugar belt. Farm household and rural business depends on the injection of cash derived from sugarcane. The survival of small towns and markets places is also dependent on the incomes from the same. The Sugar Industry is therefore a key contributor to the attainment of millennium development goals of poverty reduction and national development Wawire *et al*., (2011).

1.1.3 Genotype by environment interactions (GEI).

Genotype × environment interaction (GEI) refers to change in relative performance in a character of genotypes tested in more environments. Interactions may involve changes in rank order for genotypes between environments which includes genetic, environmental and phenotypic variances between environments. G × E results in genetic values varying from one environment to another and great genetic gains can be achieved through developing specific genotypes for each environment (Windhausen *et al*., 2012). G × E complicates selection and testing of plant genotypes. In the absence of G × E interaction, the superior genotype in one environment may be regarded as superior genotype in all, where as the presence of G × E interaction confirms particular genotypes being superior in specific environments. In plant breeding programmes desirable genotypes are selected

after evaluation of many potential genotypes under different varying environments (locations and years). If G × E interaction is large it may result in failure to differentiate performance of genotypes across environments. G × E I has a greater influence on yield and quality of sugarcane and this influences precision in selection. In sugarcane the effects of G × E are largely controlled by locations, planting or harvest period and crop years. (Kimbeng *et al.,* 2009). Studies conducted on G × E reported significant G × L for sugar yield and brix in western Kenya. Jamoza, (2011).

1.2 Problem Statement

The Sugar Research Institute (formerly KESREF) breeding programme is one of the pioneer breeding programmes in Eastern and Central Africa (Jamoza, 2005). The crossing of sugarcane parents is done at the Sugarcane Breeding Center Mtwapa (SBC) in the Coast region of Kenya since the climate favors natural flowering of sugarcane and good seed set. The objective of the breeding programme is to develop varieties that have improved cane and sugar yields, are resistant to the biotic and abiotic stresses and adapted to cane growing conditions in Kenya (Jamoza, 2005). Sucrose content in sugarcane is a highly desirable trait and cultivars differ in their capacity to accumulate sucrose. It is among the key characters given consideration in the development of varieties hence an important economic quality parameter of sugarcane juice. It is therefore important to determine the magnitude of the impact of environment on sugarcane sucrose content. Sucrose accumulation in sugarcane is determined by the genetic potential of a variety and environment under which it is grown.

Limited studies have been undertaken to determine the influence of G × E on sugarcane sucrose content in Kenya. Many G×E studies worldwide have little application to Kenyan scenario since they are performed under controlled environment with shorter crop maturity. When sugarcane cultivars are tested in contrasting environments, their performance may vary (Kang and Miller, 1984, Nagarajau and Ethirajah, 1988). Sugarcane breeding programme in Kenya has not fully exploited the potential in sugarcane variety testing in diverse production zones mainly in the Coast, Western Kenya, Nyando and Transmara zones with specific attention to sucrose content in its selection scheme.

An exploratory study was conducted in Mumias on the genotype by environment interactions (Jamoza *et al*., 2008). Three commercial cultivars and four semi-commercial cultivars were tested in one location on two different soil types. The study indicated the presence of G×E interactions for major sugarcane economic traits such as sucrose and yield. Recommendations from the study were that further work with large number of genotypes in more environments should be carried out in order to avail more information on the interactions as this will improve the efficiency in sugarcane variety selection. This study had two major limitations that included the number of testing sites which were not fully representative of the entire sugar industry in Kenya. Secondly few numbers of varieties were tested in one location.

This study, therefore sought to fill the existing knowledge gap by increasing locations and testing more genotypes in varied sugarcane production zones by focusing precisely

on the effect of G × E on sugarcane sucrose content. Generation of in depth knowledge on G×E would contribute to improvement in the sugarcane selection efficiency of this trait in Kenyan sugarcane breeding and selection scheme.

1.3 Justification

In the process of variety development, appropriate evaluation and selection of promising genotypes is a key element for consideration by the plant breeder. Performance of the genotypes in various traits across locations offers the breeder an opportunity to evaluate them for their potential hence selection of promising lines.

There is need to carry out research in this area to provide more information on G × E interactions in relation to sugarcane sucrose content. Jamoza, (2011) reported significant G×L for sucrose content, sugar yield and brix. Through this study, information on the magnitude of genotype and environment interaction in sugarcane sucrose content in three locations will be availed and enhanced. Sugarcane sucrose content is affected by many environmental and managerial factors. Information obtained will contribute to improvement in the selection efficiency for sucrose content sugarcane.

The current paradigm shift in sugarcane production in Kenya proposes cane payment based on sucrose content (The crops Act 2013). Plant breeders are therefore challenged to develop high sucrose varieties. This study aims to evaluate promising sugarcane clones in three environments viz, South Nyanza, Western Kenya with respect to sucrose content.

Information from this study will enrich the knowledge on G×E interactions and identify suitable sugarcane clones for these zones.

1.4 Objectives

1.4.1 General objective

- To contribute to the development of effective selection criteria and strategies for the sugarcane variety improvement programme.

1.4.2 Specific objectives

- To avail and enhance information on the magnitude of genotype × environment interaction on sugarcane sucrose content.
- To evaluate 22 sugarcane genotypes for sucrose content and agronomic traits in Western Kenya.
- To identify promising lines of sugarcane for further testing.

1.4.3 The null hypothesis

- The magnitude of genotype by environment interaction on sugarcane sucrose content is similar in all the environments.
- All sugarcane genotypes will exhibit no variation in sucrose content and agronomic traits across the locations.
- Same promising genotypes will be selected in this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Botany of Sugarcane

Sugarcane (*Saccharum spp. hybrid)* is a genus of between 6 to 37 species of tall perennial grasses native to warm temperature to tropical regions of the world. It belongs to the *Poacea* family and of the *Andropogonae* tribe. The plant is made up of roots, stems and leaves. The stalk exists above ground. It is economic important because it is the source for sucrose storage. The stem comprises of internodes, nodes, lateral bud and root bands. It is also used for vegetative propagation and supports the leaves. The leaves are attached to the stem alternating for efficient capture of the sunlight. All the sugarcane species interbreed and the major commercial cultivars are complex hybrids (American alternative energy systems cooperation (AAESC, 2008).

2.2 Sugarcane agronomic traits

2.2.1 Germination

Sugarcane germination is a process of development of small shoots enclosed in the bud scales. This development is affected by both plant physiological and environmental factors mainly temperature and soil moisture. Optimum temperature for germination range between 27^0C-37^0C while the soil moisture particularly in the top 10cm is critical for cane setts root development. Germination of bud is influenced by both external and internal factors. The external factors are soil moisture, soil temperature, and aeration. The

internal factors are the bud health, sett moisture, sett reducing sugar content, and sett nutrient status. Good germination is a basic requirement for higher sugarcane and sugar productivity. Sugarcane varieties differ in their degree of temperature sensitivity but germination is generally slow at soil temperatures below 18^0c but becomes more rapid up to about 35^0C Bull (2000). Sanghera *et al*., (2015) reported that cane yield is significantly correlated to number of milleable stalks, stalk length and germination (45 days after planting) indicating the importance of these traits in selection criteria.

2.2.2Tillering

The second phase of cane development is known as tillering. The tillering rate and duration has influence on the subsequent phase and final yield. Apart from varietal characteristics tillering is also influenced by light, soil moisture, temperature, nutrients and spacing. The optimal temperature for tillering is 30^0C while (N) and phosphorous (P) levels of 100-150kg ha^{-1} and 80-100Kg $ha^{-1}P_2O_5$ favors tillering. Nitrogen not only influences tiller emergence but also survival. Increased tiller population results in enhanced number of mature stalks and this contributes significantly to sucrose production. Tiller production has been found to be associated with sugarcane quality Ahamed *et al*. (2010).

2.2.3 Ripening

During ripening there is an increase in sucrose content in the sugarcane stalks. The optimal conditions for sucrose accumulation in the stalks are those that favor the photosynthesis during the day and reduced growth at night. A mature cane stalk

constitutes about 75% of the entire plant. It is typically composed of 15%-18% fiber, 12%-16% soluble sugars, 2%-3% non-sugars and 63%-71% water. Ripening is affected by variety, nitrogen, soil moisture, sunshine hours and amount of sucrose in the sugarcane to be transported from the leaves to other parts of the plant via the leaf sheath. Sucrose synthesized during a 24 hour period is partly stored in the mature ripening internodes and the rest finds its way to the root system, the apical region and sometimes to the other suckers of the same stool. Both amount and rate of sucrose translocation in sugarcane are affected by environmental factors. Optimal temperature for sucrose translocation is 35^0C but no movement occurs at 5^0C .Young stalks contribute more sucrose towards growth process while in older ones storage predominates (MSIRI, 2000).

2.3 Sugarcane varieties grown in Kenya

The main sugarcane varieties grown in Kenya are Co 421, Co 617, Co 945 and N 14. These together occupy more than 65% of total sugarcane acreage Jamoza, (2013). Other commercial varieties are Co1148, EAK 70-97, and CB38-22. The varieties like Co421 and Co617 which dominate in Nzoia and Nyando sugar zones are characterized by late maturity, low sucrose content and are susceptible to major diseases like smut, mosaic and ratoon stunting while varieties such as N 14 and Co 945 dominate the Mumias and South Nyanza sugar zones Jamoza, (2013). The sugar Research Institute (SRI) has made great strides in development of improved sugarcane varieties for the Kenyan sugar industry. Since the year 2002 (SRI) has developed 21 improved varieties with enhanced attributes viz early maturity, high sucrose content and high yields, tolerance to biotic and a biotic stress. Some of the varieties developed by (SRI) and have gained wide adoption are KEN

83 - 737, D8484, EAK 73 - 335 , KEN 82 - 472, KEN 82 - 601, and KEN 98 - 530. Kenya remains insufficient in sugar production which has resulted in the importation of the deficit to bridge the gap. These improved varieties have the potential of turning around the sugar industry in terms of cane yield and sugar productivity

2.4 Factors affecting sugarcane sucrose content

2.4 1 Altitude

Sugarcane quality is affected by several ecological, cultural, physiological and biological factors. Sugarcane is generally grown at low altitudes in most countries. In Kenya it is grown in a range of altitudes between 1100 - 1600m above sea level. At low altitude of Kenya's coastal region, (15 and 450 masl in Mtwapa and Kwale) sugarcane matures between 10 to 12 months while in western Kenya maturity period ranges from 16- 24 months depending on the variety (Jamoza *et al*., 2013).

2.4.2 Rainfall

Total annual rainfall between 1100 and 1500 mm is adequate provided the distribution is uniform, abundant in the early period of vegetative growth followed by a dry period for ripening. During the active growth period rainfall encourages rapid cane growth, cane elongation and internodes formation. However during ripening period high rainfall is not desirable because it leads to poor juice quality, encourages vegetative growth, formation of water shoots and increase in the tissue moisture (NETAFIM, 2012).

An average of 1200 mm evenly distributed rainfall in the range of 1100-1500mm is optimum for higher yield. However, good production are also being taken in the regions having a minimum of 600 mm to a maximum of 3000 mm rainfall, which depends on adoptive measures, selection of varieties and farming methods (ICAR, 2000).

2.4.3 Temperature

Growth is closely related to temperature. Greater range between maximum and minimum temperature has been known to increase sucrose content in cane juice. Optimum temperature for sprouting (germination) of stem cuttings is 18° to 38°c. Temperatures above 38° reduce the rate of photosynthesis and increase respiration. For ripening, relatively low temperatures are desirable, since this has a noticeable influence on the reduction of vegetative growth rate and enrichment of sucrose accumulation in the stalk. Sugarcane productivity and juice quality are profoundly influenced by weather conditions prevailing during the various crop growth sub-periods. Sugar recovery is highest when the weather is dry with low humidity, bright sunlight hours, cooler nights with wide diurnal variations and very little rainfall during ripening period. These conditions have been found to favour high sugar accumulation. Climatic conditions characterized by very low temperatures deteriorate juice qualities thus affecting sugar quality. Favorable climate that is warm and humid climate favours insect pests and diseases which cause much damage to the quality and yield of its juice and finally sucrose content. (**www.sugarcanecrops.com**)

2.4.4 Relative humidity and wind velocity

High humidity (80-85%) favours rapid cane elongation during grand growth period. This results in a higher percentage of glucose and poor percentage of sucrose. A moderate value of 45-65% relative humidity coupled with limited water supply is favorable during the ripening phase. High wind velocity after stem elongation results in lodging of the stalks and this converts sucrose into glucose which impairs quality of cane.

2.4.5 Sunlight

Sugarcane is a sun loving plant. It grows well in areas receiving sufficient solar energy. Being a C_4 plant, sugarcane is capable of high photosynthetic rates and the process shows a high saturation range with regards to light. Tillering is affected by intensity and duration of sunshine. High light intensity and long duration promote tillering while cloudy and short days affect it adversely. Stalk growth increases when daylight is within the range of 10 - 14 hours. Increase in leaf area index is rapid during 3rd to 5th month, coinciding with the formative phase of the crop and attained its peak values during early grand growth phase.

2.4.6 Soils

Soil is a media that provides nutrients, water and anchorage to the growing plants. Effects of soils on juice quality in sugarcane appear to be greater than on yield. Maintenance of proper physical, chemical and biological conditions of the soil is necessary for realizing higher growth, yield and quality of sugarcane. Sugarcane can be

successfully raised on diverse soil types ranging from sandy soils to clay loams & heavy clays.

A well-drained, deep, loamy soil with a bulk density of 1.1 to 1.2 g/cm^3 (1.3-1.4 g/cm^3 in sandy soils) and total porosity, with an adequate balance between pores of various sizes higher than 50%, ground water table below 1.5 to 2.0 m from soil surface and an available water holding capacity of 15% or more (15 cm per meter depth of soil) is considered ideal for sugarcane cultivation. (www.sugarcanecrops.com).

Higher salt content depresses the juice quality in sugarcane. Similarly, cane grown on soils with high or lower pH results in poor quality. The optimum soil pH is about 6.5 but sugarcane can tolerate considerable degree of soil acidity and alkalinity. Hence, it is found growing in soils with pH in the range of 5 to 8.5. Liming is required if pH is less than 5.0, or gypsum application if pH is more than 9.5. Soils rich in calcium or rich in lime (Cao /$CaCo_3$) produce better quality cane juice compared saline soils. Sugarcane juice quality is reduced by soil salinity since it affects juice ionic composition, and osmolality. Saline soils have been known to result in higher levels of molasses content than cane juice Lingle *et al.,* (1997). Salinity of the soils has been shown to reduce Pol (percentage of sucrose in juice), Salinity also increases juice electrical conductivity; a measure of mineral content. Lingle and Wiegand, (1997) showed increasing electrical conductivity of saturated soil extract (ECe) decreases Pol%, Brix% and apparent purity%. Also juice Na+, K+, Ca2+, Mg2+and Cl- increase with ECe and most of the increase in juice electrical conductivity was due to increase Cl-. Therefore soil testing before

planting is desirable as it helps in determining the optimum quantity of macro and micro nutrient application. Chemical constraints in the soils, such as acidity and low fertility, should be controlled for optimum yields Singh *et al*., (2005).

2.5 Cultural Factors

2.5.1 Fertilizer types and application

Heavy feeding of sugarcane with nitrogenous fertilizers results in delayed maturity of cane and poor juice quality as it prolongs vegetative growth. The time of application also has great impact, for instance late application of nitrogen results in more glucose and molasses content in juice which impairs quality. Azazy *et al*., (2000) found that increasing nitrogen fertilizer application upto 210 kg N increased cane and sugar yield. El-sayed *et al*., (2005) showed that increasing nitrogen fertilizer application up to 240 kg N significantly increased cane yield. Bekheet *et al*., (2001) and Kamel *et al*., (2007) found that increasing nitrogen fertilizer up to 240 kg N gradually increased total soluble solids, sucrose, juice purity and sugar recovery percentages.

Phosphorus reduces nitrogen and acid content in cane juice and increases the ash content. It also prevents crop lodging. LakshmiKantham *et al*., (1983) found that application of phosphorus at 112 kg P_2O_5 ha^{-1} gave the highest yield and quality of sugarcane. Ismael *et al*., (2000) obtained a significant influence due to application of phosphorus on juice quality and sugar yield up to 60 kg P_2O_5 fed. El-Soghier, (2003) and El- Sayed *et al.*,

(2005) showed that increasing phosphorus fertilizer up to 90 Kg P_2O_5 ha^{-1} increased juice quality, cane yield, and sugar yield in tonnes.

Potassium has a distinct role in sucrose transportation and accumulation in the storage tissues of the plants. Maqbool and Akhtar, (2002) stated that cane yield and sugar yield increased with application of 150 kg K_2O ha^{-1}. (Bekheet and Abo El- Wafa, 2006) found that increasing K up to 96 Kg K_2O ha^{-1} significantly increased juice quality and cane yields. Application of boron plays a major role in improving sucrose quality well as application of organic manure which gives better results in enhancing cane quality.

2.5 .2 Irrigation

Light and frequent irrigations have been found to be beneficial in improving juice quality while excessive irrigations lead to water logging, crop lodging and excessive branching reducing the quality of juice. Other cultural operations such as detrashing, defoliation have indirect effect on quality of juice. Thomas *et al*., (1981) found that saline irrigation did not consistently decrease Pol and Brix. Earthing up and increasing depth of planting furrows have been found to increase the sucrose percentage in the cane juice. Pests such as borers, white fly with diseases such as wilts and necrosis have been found responsible for poor quality of juice in sugarcane. In certain places such as India planting season affects the quality of juice since harvesting is governed by the planting season of the crop. A good example is the spring planted cane which tillers for only five months before harvesting producing lower quality juice with lower sugar percentage as compared to autumn planted cane Singh, (2005).

2.6 Influence of sugarcane varieties on sucrose quality vs cane quality

Sugarcane quality is affected by factors such as fibre, trash at harvest, staleness, moisture content of the cane, pests and diseases, stress factors and physical damage during mechanical handling Clarke *et al*., (1996). Due to genetic variability different genotypes behave differently to post harvest deterioration (Shinde *et al*., 1985). The genetic and morphological nature of the cane such as thickness, rind hardness, wax coating contributes to the extent of deterioration. Crop maturity affects the quality of sucrose. Immature or over mature cane deteriorates faster in hot weather. Post-harvest deterioration has shown a steep decline in juice quality after 48 hours of harvest at in mature crop when temperature and humidity are high (Rupa andAsokan 2008).

2.7 Sugarcane harvesting practices

According to Foster and Irvin, (1981) pre- harvest burning of sugarcane in some western countries viz. Australia, Jamaica causes major physic-biochemical changes in cane plants. These metabolic changes along with microbial infestation and other factors such as thermal destruction of sucrose, high inversion rate, water loss and loss of sugar by exudation on cane surface are additional reasons for lowering commercial cane sugar (CCS) value of burned crop. Good harvesting practices in sugarcane production enhance quality sucrose. An increase in levels of trash and mud causes a decrease in pol. It has been observed that appreciable amount of sugar is lost during time lag between harvesting to milling, even in well managed mills. It has been shown that increasing levels of fibre in cane can decrease pol of first expressed juice, although increasing quantities of maceration water in mills can help to increase extraction. Since fibre creates

more mill wear and tear breeders normally select against this trait. However with the current interest in cogeneration of electricity, increased fibre content has taken a new value and high fibre may become desirable breeding trait in fibre deficient areas (Asokan and Rupa, 2005).

2.8 Physiological factors affecting sucrose quality

Sugarcane sucrose quality is affected by several physiological factors. Lodging of canes distinctly lowers the juice quality due to sprouting and rooting of the lodged canes while drought conditions results in an increase in reducing sugars at the expense of sucrose and this hampers sugarcane quality. In tillering mother plants have more sucrose content than tertiary tillers because of their age. Apical tillering or branching causes depression in juice quality due to utilization of sugar by emerging tillers. Arrowing canes have been found to be rich in sucrose especially if harvesting is done soon after flowering. The portion of the cane stalk harvested also determines the quality of juice NgkeeKwong *et al*., (1994). Top internodes of cane have poor juice purity along with total solids as compared to bottom internodes. Post-harvest stalling of sugarcane has been found to cause a lot of deterioration on quality Singh *et al*., (2005).

2.9 Components associated with cane yield

Profitability of sugarcane crop depends primarily on the tillers produced which in turn dictate the final number of harvestable stalks. Sugarcane yield partly depends on initial density of primary shoots and their tillers. These in turn are influenced by number and quality of setts planted (Collins, 2002). Key components of sugarcane yields t $ha^{-1}$are

number of milleable stalks and weight of the stalks. Other components are length of individual cane stalks, stalk thickness or diameter and number of internodes. Reddy and Reddy, (1987) found that stalk number per plot had greatest influence on cane yield, followed by stalk weight. Among the characters associated with cane yields, population of the stalks at harvest showed the highest correlation followed by diameter and height of stalks Punia, (1983).

Association of these characters can influence yield both positively and negatively Ahmed *et al.,* (2010) found that association of tiller numbers with sugarcane characters such as height, girth was negative but positive with all the quality traits with an exception of fibre. Stalk height was negatively associated with all the quality traits but positively associated with cane yield, number of milleable stalks, stalk weight and internodes. Internodes were negatively associated with quality but positively associated with diameter and stalk weight. High positive and direct contribution to cane yields was reported by Sanghera *et al*., (2015) for growth characters like number of shoots, number of milleable stalks, single cane weight and girth. These growth parameters were strong contributors to cane yields which confirm earlier reports by Milligan *et al*., (1990) and Guddadamath *et al*., (2014) who reported that stalk number and stalk girth as the most important determinants of cane and sugar yields.

2.10. Components associated with sugar yield

Sugarcane varietal improvement programmes revolves on breeding of varieties with high cane yields and high sugar contents suitable for specific climate conditions. Various traits

are associated with variations in cane sugar and yields. The components of sugar yields are: tonnes of cane per hectare, and sugar or sucrose content (Skinner *et al.*, 1987). Sugar yield per hectare is mainly dependent on tillers per plant, cane yield, pol % and commercial cane sugar. Khan *et al.*, (2013) found that more tillers, good cane weight endowed with better pol% cane and purity are the most important characters for consideration in the selection for higher sugar yields in sugarcane genotypes. Ahamed *et al*., (2010) showed that quality i.e. (brix, pol % cane and purity) had a negative association with single stalk weight but a positive association with cane yield and number of milleble cane. Brix had a negative association with pol, purity and fibre but showed a positive association with cane yield and number of milleable stalks. Percent pol juice, purity and fibre showed a negative association with cane yield and number of milleable stalks. Recurrent selection in Louisiana has been reported to enhance sucrose content. Breaux, (1984) reported that four cycles of recurrent selection for sucrose resulted in an increase in sucrose content in sugarcane. In addition Lingle *et al.,* (1997) reported six cycles of re-current selection primarily had increased sucrose % cane from 11.7 to 14.0 % thus recurrent selection has been effective in increasing sucrose yield in sugarcane in Louisiana.

Sugarcane represents a unique source-sink through storage of assimilates at high concentrations in form of sucrose and this occurs in the stalks (culms). In order to encourage the increase of sucrose yields in this crop, sugar industries around the world have encouraged the development and utilization of new molecular techniques to improve mechanisms that regulate sucrose accumulation (Lakshmanan *et al.,* 2005). This

has led to the identification of several molecular markers for increased culm sucrose accumulation that are being utilized in concert with conventional breeding programmes to improve performance (Snyman *et al*., 2008). Despite all the efforts little progress has been made because conventional breeding has already maximized sucrose accumulation in the culm tissue (Grof and Campbell, 2001.). Accumulation of more sucrose content may be limited by the narrow genetic base of germplasm currently used in sugarcane breeding programmes (Jackson, 1992).

2.11. Sugarcane sucrose payment system in Kenya

Since inception of the Kenyan Sugar Industry sugarcane payment is pegged on tonnage as opposed to other countries where price of sugarcane is based on sucrose content. At the moment sugarcane prices are not uniform across all the sugar zones because they are determined by individual milling companies based on supply of sugarcane. Competition of sugarcane among millers has resulted in ever shifting prices from one zone to another.

From early 2000 with the Kenya Sugar Act 2001, Kenya has made attempts to pay sugarcane based on quality. The first pilot cane testing unit (CTU) was installed at Nzoia Sugar Company with the main objective being to determine the economic viability of the shift from weight based to sucrose based payment system.

A preliminary study undertaken comprising of two modes of payment system by Kipruto *et al*., (2015) at Nzoia Sugar Company cane testing unit indicated that sucrose based payment system was economically viable and sustainable since prices were 7%

(excluding share value of by products) better than the current weight based cane pricing system. This system was found to be rewarding and is expected to benefit efficient farmers and millers in the industry hence improve adoption of new technologies including improved sugarcane varieties which are high in quality.

2.12 Sugarcane breeding and evaluation

Successful production of sugarcane in Kenya is entirely dependent on continuous development and supply of improved high yielding cultivars by Sugar Research Institute. Natural flowering occurs at Mtwapa where SRI undertakes its breeding works. Parents in the germplasm are crossed according to specific breeding objectives and crosses generated annually.

Seedlings are established in the nursery at Mtwapa. Evaluation is done in different stages from single plant level through fully replicated cultivar trials in later stages. Selection priorities in Kenya include high sugar; yielding ability and pest disease resistance (Jamoza; 2003, 2005). There are currently 30 commercial cultivars in the Kenyan sugar industry. However only 12 of these varieties contribute significantly to both cane and sugar yield production.

2.13 Effect of G× E on sugarcane cane yield and sugar components

Three case studies were carried out in Florida to examine the effect of genotype, environment and time of harvest on sugarcane yields of newly released cultivars. The effect of environment was significant on TCH, KST, and TSH in all the three case

studies. Time of harvesting and genotype effect was highly significant .The interaction of environment x time of harvest was significant for KST and TSH but in significant for TCH in one case study. This study had several limitations in that the number of locations used in the study was not uniform in both the crop cycles tested. The number of cultivars used in this study also varied from one season to another. Another limitation in this study was the range in planting season which was too long hence bound to be affected by the changing environment Gilbert *et al.,* (2006).

Zhou *et al*., (2015) studied the locational and seasonal effects on genotype performance for cane yield and sucrose content in irrigated regions of South Africa. Seasonal differences were highly significant and so were location by season effects. Genotype by location by crop, Genotype by season by crop and Genotype by location by season by crop interaction effects were non-significant. For sucrose content all the effects with an exception of location, G×L×S×C were significant. The study had its limitations in different number of varieties tested from one season to another hence lacked consistency in terms treatments used hence difficult to ascertain the performance of an individual variety over locations. Another shortcoming in this study is it had limitations of locations since trials were conducted in two sites which may not have been fully representative of the entire sugarcane growing zones.

Zhou *et al.,* (2011) carried out another study on components of G×E among SASRI regional breeding and selection programmes and their implications. The study objectives were to determine whether G×E was present for sugar yield and its components (cane

yield and sucrose content) in secondary variety trials and determine statistical significance, relative importance implications of variance components. Different genotypes were planted from one season to another and they ranged from 24 to 36. Results obtained indicated the genotype effect was dominant hence indicating high levels of stability among the genotype populations. G×C effect was non-significant for sucrose content indicating that seasons had no influence on this trait.

Syed *et al*., (2008) studied genotypic variability in sugarcane for ratoon stunting ability. Five sugarcane genotypes along one check cultivar were used in the study. Results obtained indicated significant genotypic differences in cane yields, sucrose content and sugar yields. Sugar yield was positively correlated with refractive brix, cane yield and sucrose content but negatively associated with other parameters. The study was done in one location hence the effects of locations were not captured in the study. Few test varieties were used in this study hence not fully representative of a wide range of commercial cultivars planted in Pakistan.

Ramon *et al.,* (2002) tested fourteen genotypes against three check varieties in a randomized complete block design with three replications in six locations to study G×E in sugarcane yield and quality in Venezuela. The study objective was to determine the relative magnitude of G×E interaction effects and to evaluate phenotypic stability in sugarcane. Results obtained indicated that genotype, genotype x location, crop-year, crop-year by genotype and crop year by location interactions were significant for both traits. These results were in agreement with Jackson *et al*., (1991) and Jackson and

Hogarth, (1992) who found out that clone by location interactions were more important than clone by crop year interactions.

Repeatability of G×E aspects is an important factor in designing more efficient programmes. Mirzawan *et al.,* (1994) evaluated sugar yield from 71 environments over three year period in Queensland. ANOVA and pattern analysis was conducted. Results obtained from the study indicated each location generated a different pattern of discrimination among the clones hence emphasizing the importance of crop by location interactions and the need to concentrate on locations than ratooning ability within a location. This study agrees with findings of Jamoza *et al.,* 2011; Jackson and Hogarth, (1999). Most of these studies have attempted to provide information on the extent of influence of environment on yield and quality of sugarcane. This information correlates well with most findings in the current study of G×E on sugarcane quality in three locations in Kenya.

2.13.1 G × E under rainfed and irrigated conditions

Investigations of mega environments are a pre requisite for any meaningful variety evaluation and recommendation procedures (Yan and Hunt, 2011). In South Africa information on contribution of variety, site, ratoon and their interaction is lacking. Ramburan *et al*., (2011) conducted 43 trials in 18 locations and harvested over one to six ratoons. All trials were planted in a randomized complete block designs with four to six replications. The results obtained provided valuable insights into the nature of G × E interactions characterizing the rainfed part of the industry. The large component of

variation within this trial was accounted for by the genotype × trial interaction relative to genotype × ratoon interaction which highlighted there may be no much value in extending trials to longer ratoons. It follows that in order to enhance selection much emphasis should be placed in on sampling more trial sites than on testing ratoons within a trial.

Ramon *et al.,* (2002) evaluated 14 genotypes and three commercial cultivars under rainfed conditions in Central -Western region of Venezuela with an objective of determining the relative magnitude of G × E interaction effects. There were significant differences in genotype × location, crop-year, crop – year × genotype and crop-year × location for the two traits mainly pol and TCH. Variance due to crop year × genotype and crop- year location were significant, revealing that ratooning ability and more than one sites should be considered in the final stages of selection.

In Kenya, Jamoza, (2011) evaluated 14 genotypes in three locations under rainfed conditions. Significant differences among genotypes for all the traits were observed. The study suggested that evaluation of sugarcane clones in many locations as opposed to crop years would be satisfactory. Mirzawan *et al.,* (1993) recommended that more emphasis should be placed on sampling a greater number of locations than on testing of clonal ratooning ability within locations.

A study was conducted by Zhou *et al.,* (2009) to investigate the location and seasonal effects on genotype performance for cane yield and sucrose content and their implication

in breeding varieties for the irrigated regions of South Africa. Seasonal effects were larger than location effects, while genotype × season was larger than genotype × location, indicating the importance of seasons when breeding for irrigated regions.

Zhou *et al.,* (2011) conducted a study to determine the variance components of G × E and evaluate their relative importance in both irrigated and non-irrigated trials in seven cane growing regions of South Africa. The genotype by location was more important for the irrigated and coastal long cycle than short cycle. Genotype by crop year was more important for rainfed than irrigated indicating the breeding and selecting for ratooning ability was more was more essential for the rainfed regions. Genotype by location by crop year was more important for yield than sucrose content. In Kenya little work has been done on sugarcane G×E under irrigation making it difficult to conclude the effect of irrigation and the resulting interactions.

2.13.2 G× E on crop time of harvest

Gilbert *et al.,* (2004) conducted a trial in five locations in Florida. Some locations were repeated in different years across two cropping seasons. The effect of environment was significant on KST, TCH and TSH in all the three studies. Time of harvest had a significantly effect on KST, TCH and TSH while the effect of genotype was highly significant on KST in all the three studies. The interaction of environment × time of harvest was significant for KST and TSH while genotype × environment interaction term was significant for KST and TCH.

In view of the above findings sugarcane G×E studies have resulted in varying magnitudes of interactions. Jamoza *et al*., (2011) found testing in more locations to be more important that crop cycles while Zhou *et al*., (2009) found seasons more important than crop locations in irrigated crops. Ramon *et al*., (2002) found both locations and crops to be more important when selecting for superior genotypes. It follows that environmental factors mainly soil, water regimes, temperatures and crop management plays a big role in determining these interactions in sugarcane.

2.13.3 Effect of sugarcane diseases on sugar recovery

Sugarcane diseases are constraints to crop production all over the world and no country is immune to the destructive influences of plant pathogens. Key disease affecting sugarcane in Kenya is smut, mosaic virus, ratoon stunting and rust diseases. The major insect pests are stalk borers, shoot borers and termites. Nzioki *et al*., (2007).Many diseases cause considerable loss in yield and quality of sugarcane. Red rot affected canes gives poor recovery because it causes impaired sucrose metabolism. Red rot infection on variety CoC671 drastically reduced brix sucrose per cent and purity (Viswanathan and Samiappan, 1999). The affected cane recorded 25% lower sucrose than healthy cane. Smut infection in Tamil Nadu was reported to adversely affect juice quality parameters. Infected cane contained more reducing and less sucrose than the healthy stalks (Sankapal and Nimbalkar, 1979). Estimation of juice quality parameter of sugarcane mosaic virus infected cane revealed that virus infection caused significant reduction in brix, sucrose and purity values. Commercial cane sugar yields were reduced upto 10% (Balamuralikrishnan *et al*., 2004).

2.13.4 Analysis of G × E interactions in sugarcane

Despite the wide range of available techniques to analyze G×E interactions, their applications to sugarcane are limited in comparison with other field crops. The majority of studies of G × E interactions of sugarcane fall within the empirical category, where the focus was on genotype stability and identification of homogenous environments within breeding programs (Kang and Miller, 1984; Tai *et al*., 1982). Jackson *et al.,* (1991) used ANOVA, cluster analysis and PCA to investigate the G × E interactions of three datasets of sugarcane pre-release trials in Australia. In that study significant G × E interactions were observed in all three datasets, and it was concluded that testing across sites was more important than testing across ratoons within sites for identification of superior clones. Rattey and Kimbeng, (2001) used variance components analyses to estimate the magnitude of G × E interactions and determine optimal resource allocation in final stage selection trials in the Burdekin district of Australia. They found that genotype × crop (ratoon) contributed more to G × E interactions than genotype ×location x ratoon and genotype × location interactions, respectively.

A limited number of sugarcane G × E studies have employed multivariate techniques. Bissessur *et al*., (2001) showed that AMMI was more effective than ANOVA at identifying significant G × E interactions in a study of final stage selection trials in Mauritius. They found that AMMI was effective at identifying cultivars with broad and specific adaptation and recommended that the technique be routinely used to obtain additional information on clones prior to their commercial cultivation. Similarly, Queme *et al.,* (2001) and Queme *et al.,* (2005) demonstrated that AMMI could be successfully

employed to analyse G × E interactions and identify specific cultivar adaptability of sugarcane METs in Guatemala. In India, Srivastava *et al*., (1999) showed that AMMI was more accurate than the sites regression model (Finlay and Wilkinson, 1963) as it captured a greater percentage of the G × E interaction sums of squares in an analysis of eight sugarcane cultivars in a MET. Redshaw *et al*., (2002) compared AMMI and restricted maximum likelihood (REML) techniques for the analysis of an unbalanced MET dataset in South Africa. That initial study showed that the dry land regions of the South African sugar industry could be divided into four mega- compared to AMMI, relatively fewer studies have employed the GGE biplot method as a tool for the analysis of sugarcane METs. Queme *et al*. (2007) employed the GGE biplot technique to group sites and identify superior cultivars in each group using MET data from a low production zone in Guatemala. Glaz and Kang, (2008) used GGE biplots to identify redundant sites used during selection in the Florida sugarcane industry. They used the technique to successfully identify locations with organic soils that, if replaced by locations with sandy soils, would be least likely to compromise the ability of the selection program to identify superior cultivars for the industry.

The G × E interactions in sugarcane have also been demonstrated using numerous variations of traditional analyses and "non-conventional" methods. Such studies have tended to focus on the crop characteristics of specific industries. For example, Gilbert *et al*., (2006) employed analyses such as repeated measures ANOVA and identified significant genotype x environment, environment x time of harvest, and genotype × environment × time of harvest interactions in Florida. Jackson *et al.*, (2007) used

restricted maximum likelihood (REML) analysis to investigate the magnitude of genotype × region interactions relative to G×E. This study showed that genotype × region interactions were small compared to genotype × environment. Interactions within regions and that indirect selection in a region different to that being targeted would be only slightly less effective than selection within the targeted region itself. In South Africa, Ramburan *et al.,* (2011) categorized post-release cultivar evaluation trials based on age and time of harvest and demonstrated highly significant genotype × age and genotype x time of harvest interactions using REML. These results were subsequently used to characterize varieties for inclusion into a decision support system.

Despite the examples of the existence of G × E interactions in sugarcane, attempts to interpret such interactions are very limited. The most recent and only attempt to interpret sugarcane G x E interactions relative to environmental factors was conducted by Jackson *et al*., (1995). That study used cluster analysis and principal component analysis to relate sugarcane family × site interactions to environmental factors. They found that key climatic factors such as rainfall, temperature and solar radiation did not appear to be important in causing family x site interactions. However, significant correlations were found between soil nutrients (calcium, copper and zinc) and the PC2 scores from PCA analysis, suggesting that these nutrients had effects on the family × site interactions. The scarcity of studies involving interpretation of sugarcane G × E interactions and the relative benefits of such studies to improvements in selection strategies, as demonstrated in other crops, suggest that more priority should be given to this area of sugarcane research. Due to the lack of widespread post-release cultivar evaluation programs in

sugarcane Ramburan and Van den Berg, (2011), most studies on G × E interactions of sugarcane have been conducted within the realms of breeding and selection. Post-release cultivar evaluation programs may also be suitable resources within which analytical (interpretive) studies of G × E interactions are possible. This is due to the wider range of environmental conditions typically evaluated, which is associated with greater representativeness of an industry.

In view of the above methods AMMI is the most effective method for G×E studied given its robustness in identifying significant G×E. In the current study AMMI could not be applied since this was a preliminary study of G×E on sucrose content with one season crop. AMMI is applied in final studies to find broad and specific adaptation and additional information of clones prior to commercial cultivation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Experimental Sites

This study was conducted in three sugarcane growing zones namely, South Nyanza Sugar Company, Mumias Sugar Company and KALRO-Sugar Research Institute farm at Kibos.

a) South Nyanza Sugar Company (lognitude34^0 24’ 00’’E, latitude 0^0, 30’ 00’’S) is in Awendo Migori County at an elevation of 1351m above sea level. The area lies in lower midland 1(LM1) agro-ecological zone with 2200 mean annual rainfall and means daily temp of 14^0c-31^0c.This area is characterized by deep red clay loam soils. (Jaetzold and Schmidt 2007).

b) Mumias Sugar Company (longitude $34^0$29’ 11.04’’ E, latitude 0^0 20’ 6.40’’N) is in Kakamega County at an elevation of 1314m above sea level, receives 2194 mean annual rainfall with a mean temperature range of 16- 30.9^0C . Mumias lies in lower midlands 1(LM1) agro ecological zone and is characterized sandy clay loam soils (Jaetzold and Schmidt, (2005).

c) KALRO- Sugar Research Institute (SRI) formally (Kenya Sugar Research Foundation) farm is at Kibos (longitude 34^0 38’’E, latitude 0^0 34’’N) in Kisumu County stands at an altitude of 1184 meters above sea level. Kibos lies within lower

midlands 2 (LM2) agro ecological Zone (AEZ) (Jaetzold and Schmidt, 2005) with a mean annual rainfall of 1490mm. Kibos has a sub- humid climate characterized by high day temperatures and cool nights with an average annual minimum and maximum temperatures of 19^{o}C and 28^{o}C respectively. The soil type is heavy clay loam and all the three zones have a bimodal rainfall pattern.

3.2 Experimental Material

Twenty-two sugarcane clones obtained from the Sugar Research Institute Sugarcane breeding programme and three standards were used in this study. The experimental clones were selected on the basis of brix which is an indicator of sucrose content in sugarcane and cane yield. They were selected from the preliminary breeding stage 3 at SRI research farm in Kibos (Table 1). Three commercial sugarcane cultivars widely grown in the country industry namely KEN 83-737, EAK 73-335 and D8484 were used as standards. The three are high in sucrose content hence a criteria for selecting them as checks.

Table 1: Genotypes selected for evaluation in three locations

Genotype		Brix (^{0})	Cane yield t ha^{-1}
1	KEN 04-100	15.3	68.5
2	KEN 04-326	13.3	39.1
3	KEN 04-419	15.8	42.2
4	KEN 04-423	14.3	37.8
5	KEN 04-710	14.3	44.8
6	KEN 04-762	14.5	46.9
7	KEN 04-1079	13.8	38.8
8	KEN 04-1320	15.3	41.2
9	KEN 04-1454	13.8	39.8
10	KEN 04-1564	13.5	34.9
11	KEN 04-1603	14.0	39.8
12	KEN 04-1809	13.8	54.9
13	KEN 04-2010	14.8	32.8
14	KEN 04-2153	13.8	28.6
15	KEN 04-2192	15.0	39.3
16	KEN 04-2274	15.8	45.8
17	KEN 04-2349	12.6	39.6
18	KEN 04-2765	13.1	31.5
19	KEN 82-121	15.5	36.5
20	KEN 82-472	13.0	49.5

21	KEN 82-493		16.2	53.1
22	KEN 82-601		15.8	47.4
23	KEN 83-737	STD	15.0	57.6
24	D 8484	STD	16.6	50.0
25	EAK73-335	STD	17.4	54.9

3.3 Land Preparation.

Suitable land for trial establishment was selected in the three sites. Land preparation involved mechanical ploughing using a disc plough in all the sites to a depth of 25- 30 cm. Harrowing was done using a disc plough to break soil clods and obtain a fine tilth to a depth 0f 20-25cm. Final operation undertaken was furrowing to attain a depth of25cm.The interow spacing was 1.2m (Jamoza, 2013).

3.4 Field Experimental Design and Layout.

The experiment was a 5×5 lattice square design with three replications comprising the twenty five treatments. The gross plot size was 4 rows of 8 m long while the net plot measured 2 rows 8 m long. Plots were separated from each other by a 2m path (Appendix 3).

3.5 Planting and Crop Management

Seedcane material aged 11 months was obtained from SRI farm at Kibos. The planting material was prepared by chopping using pangas into three eye budded setts to enhance germination. Seedrate of 8 tonnes ha^{-1} was used in the establishment of each trial,

(Omoto, 2008). Planting was done towards the start of short rain season in August 2011 in all locations.

The setts were immersed in an insecticide (Imidacloprid700gms/kg) ha^{-1} to prevent possible insect attack. Each of the 8 m row was planted with 30 setts resulting in 120 setts per plot. Planting of the setts was done by placing them in the furrows of 25cm depth using end- to- end method of planting. The setts were lightly covered with the soil using hoes to enhance germination. Application of phosphate as concentrated diammonium phosphate fertilizer (DAP) was used at planting at a recommended rate of (46% P_2O_5 ,18% N) and this was applied at a rate of 35.5kg P ha^{-1} at planting.

Nitrogen as urea (46% N) was applied for topdressing in two equal splits of 26 kg N ha^{-1} when the crop was 3 and 6 months in all the sites (KESREF, 2013). Weeds were controlled by weeding manually at a frequency of two months. A total of 5 hand weedings were undertaken.

3.6 Data collection

3.6.1 Germination assessment

Germination data was collected by counting number of shoots emerged in each net plot of 2x1.2x8M rows at 30 and 45 days after planting. This was expressed as a percentage as follows; number of shoots germinated over the total number of eye buds planted x 100.

3.6.2 Tiller Production assessment

Tiller production was assessed at 3, 5, and 7 months after planting and this involved counting the total number of tillers produced within the net plot of individual treatments.

3.6.3 Disease and pest assessment

Disease and pest incidences were assessed from 3- 7 months after planting. Smut was scored on percentage of tillers infected verses the overall tiller population in accordance with the International society of sugarcane technologists (ISSCT) rating. Sampling of pests was done according to Sutherland *et al.,* (1996). Sugarcane mealy bugs (*Saccharicoccus sacchari*) and scale insects (*Melanaspis glomerata*) were targeted due to their occurrence in these zones and likely negative effect on juice and quality through boring and sucking the juice within stalks.

3.6.4 Cane yield determination at harvest

The following yield components were assessed at harvest when the crop was 16 months old and they involved measuring the following:

a. Number of milleable cane: - A count of mature stalks within each net plot was obtained and expressed as stalks ha^{-1}. At harvest cutting of the stalks was done at ground level and all the leaves stripped off to the top visible dewlap to avoid loss in yield and quality.
b. Plant height: Six stalks randomly selected from the net plot were cut and their heights obtained from the base to the top visible dewlap using a tape measure.

c. Stalk girth (diameter): This was measured on the 6 stalksabove using a vanier caliper (Mitutoyo) and an average obtained.
d. Number of internodes was determined by counting 6 stalks from the base to the last visible node of each stalk and a mean obtained.
e. Cane Yield: Cane yield at harvest was determined by weighing all the stalks from the net plots. An automated electronic balance (KERN&SOHN Gmbh.) was used to weigh cane from the net plot of individual treatments. These weight in (Kgs) were the converted to cane yield in t ha.$^{-1}$

3.6.5 Cane quality data

A hand refractometer machine (Atago, 0-32^0) was used in field determination of brix (^{0}) cane on standing crop. Six milleable stalks were taken randomly from each plot from 8 months and used for brix extraction. At harvest mature milleable stalks in each plot were cut at the base, well topped and all the trash and green leaves removed. Twelve milleable stalks were taken randomly from each plot, tied, labeled and transported to the laboratory for juice and fibre analysis. A sample of six stalks was used for juice extraction using a three roller cane press (Milligan *et al.,* 1990).Juice was thoroughly mixed and filtered through a whatmans filter paper No 1 100 ml of the filtrate was used to determine brix using a bench refractometer as described by SchoonessMuir *et al.,* (2009). To determine pol % juice, approximately 300ml sample of juice extracted was placed in a beaker and clarified using 2g of lead sub acetate. The mixture was filtered using whatman filter paper No 91. From the clarified juice Pol (Apparent sucrose content) was read using an automated saccharimeter (Antonpaar MCP 250). A crushed and sieved cane sample of

100g was placed in an oven model BR6000 binder world at 105 ^{0} C for 4 hours then reweighed for moisture determination. From brix ,Pol reading and moisture % calculations on cane juice quality(pol% cane), fibre % cane and sugar yield per hectare were derived according to the South African Sugar Technologists Association(SASTA) formulae (Schooness-Muir *et al.*, 2009).

The six other stalks from the bundle of each treatment were used for the determination of fibre percent cane according to Clayton (1971). Six pieces were cut in equal sections top, middle, and bottom portions in order to obtain a representative sample of the whole stalk. The pieces were further chopped into smaller portions of about 2cm long and shredded in the laboratory using an automated shredder (Peruzzo TB300 ComtyElet).The shredded samples were well mixed and a sample of 200g sub samples placed in fibre bags, washed alternately in cold and hot water to remove all sugars mainly (sucrose, fructose and glucose). The samples were then dried in an air oven at 105^{0}C for 24 hours to ensure a constant dry weight of the sample.

Fibre percent cane was computed directly from both fresh and dry weight as follows:

Fibre % cane = ((100-((Brix*3) + moisture %)/(1-(Brix*0.0125))

Pol % cane = Pol % Juice x [1-(5+Fibre)]

100

Purity= Pol % cane * 100

Brix % cane

Estimated sugar yield (t ha^{-1}) = Pol % cane*cane yield (t/ha)/100

Moisture% = 100gms of wet baggase of sample – a constant dry weight of sample after 4 hour drying period.

3.7 Data Analysis

Data collected on cane growth and yield parameters were subjected to analysis of variance with blocks and environment considered as random factors given they were representative while genotypes were considered as fixed factors because they were selected as suggested by Brown and Glaz, (2001). Phenotypic correlations were computed for both quality and yield attributes.

Data for individual locations and combined analysis across the three locations was subjected to general linear model (PROCGLM) procedure of the statistical analysis (SAS release version 9.1 for windows 7) and means compared by Fischer's least significant difference (LSD) procedure according to Steel and Torrie, (1987). Simple correlations among traits were computed.

Experimental Model

The following statistical linear model was used:

$$y_{ijkl} = \mu + L_i + G_j + R_k + GL_{ij} + \varepsilon_{ijkl}$$

Where $y_{ijkl=\ observation}$ of j^{th}genotype in the k^{th}replicate and i^{th}location.

μ = General Mean,

L_i = Location/Environment effect

G_j = Genotype effect

GL_{ij} = Effect of the j^{th} genotype in the i^{th}location.

R_{ki}= Effect of the k^{th} replicate in the i^{th} location

ε_{ijk}=Experimental error effect .

CHAPTER 4

RESULTS

4.1 Performance of genotypes in formative growth components

4.1.2 Genotype germination and Tillering

Germination of genotypes varied in all the sites. The highest germination of 64.4%was recorded in Kibos followed by Mumias Sugar Company 36.79% while south Nyanza Awendo had the least germination of 19.34%. The highest tillering of 432 was obtained in South Nyanza, followed by Mumias with 271 tillers with the least tillering of 211 recorded at SRI- Kibos (Figure 1).

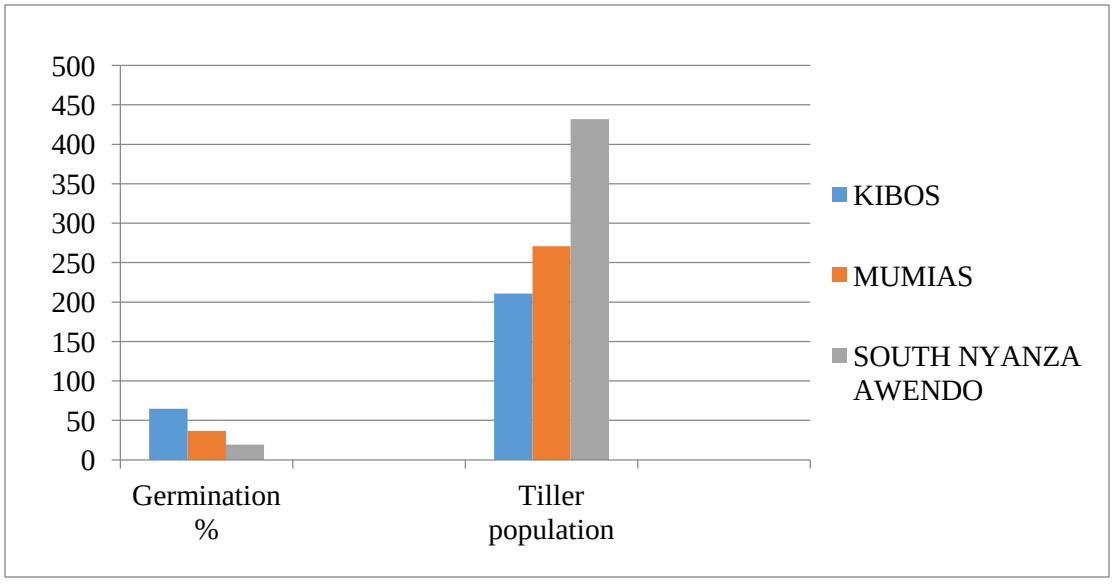

Figure 1: Genotype germination % and tiller production in Kibos, Mumias and South Nyanza

In South Nyanza germination ranged from 9.6 to 33.3 % on genotypes KEN 82 - 472 and KEN 82-601. Eleven clones performed better than the standard varieties in germination (Annex 5). Tiller production was variable amongst treatments as the highest and lowest tillering of 510.67 and 321.67 tillers was recorded on genotypes KEN 04-2765 and KEN 04 -2192. Ten clones were superior in tillering than the check varieties (Appendix 6).

Differences among genotypes were significant ($P \leq 0.01$) for germination and tiller production with an R^2 of 0.74 and 0.59 % respectively in this site. (Table 2)

Table 2: Genotype mean squares for germination at 45 days and tillering at 7 months at South Nyanza (Awendo)

Source of variation	Df	Germination %	Number of tillers
Genotype (G)	24	104.46**	8546.90**
Replication within location (R)	2	356.74	22183.89
Error	48	23.21	3540.95
Mean	-	19.34	431.78
C.V (%)	-	24.91	13.78
R^2	-	0.74	0.59

In Mumias, mean germination ranged from 22.96 to 50.56 % on genotypes KEN 82 - 601 and KEN 04 -710. Ten test treatments were better in germination than the standard

varieties. (Annex 7). Mean tiller production ranged from 118 to 372 on KEN 82-121 and KEN 04-419 respectively. Six treatments tillered higher than the standard varieties. (Appendix8).

Significant genotypic differences were not detected in germination at Mumiaswhere as significant differences were detected in tillering ($P \leq 0.01$) with an R^2 of 0.34% and 0.78 % (Table 3).

Table 3: Means squares for genotypes effect on germination at 45 DAP and at 7 months in Mumias

Source of variation	Df	Germination %	Number of tillers
Genotype (G)	24	195.22	11724.18**
Replication within location (R)	2	45.31	925.96
Error	48	194.40	1710.90
Mean	-	36.79	270.76
C.V (%)	-	37.90	15.28
R^2	-	0.34	0.78

**= Significant at p≤0.01 *=Significant at p≤0.05

Germination at Kibos ranged from 33.3 (KEN 82-601) to 84.07% (KEN 04-1603)Eight clones had better germination than standards (Appendix 9).The highest and lowest mean tiller of 128.67and 266.33 were recorded on genotypes KEN 82-121 and KEN 04-326.

Seven genotypes were better in tillering as compared to the standard varieties (Appendix 10).

Genotypes differed significantly in germination and tillering at Kibos(P≤ 0.01) with an R^2 of 0.62% and 0.76% in germination and tillering respectively in Kibos (Table 4)

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Table 4: Mean squares for genotypes effect at 45 DAP and tiller at 7 months in Kibos

Source of variation	Df	Germination %	Number of tillers
Genotype (G)	24	378.29**	1947.97**
Replication within location (R)	2	88.60	3011.08
Error	48	5637.34	349.09
Mean	-	64.64	210.80
C.V (%)	-	16.76	8.86
R^2		0.62	0.76

**= Significant at p≤0.01 *=Significant at p≤0.05

4.1.3 Combined genotype germination and Tillering

Genotypes differed significantly in germination (P≤ 0.05) in the three locations. There were significant G×L interactions (P≤0.05) (Table 5). Tillering ability differed significantly (P≤0.05) from one location to another. Genotypes differed significantly in tillering (P≤0.05).(Table 4.4). Significant G×L was recorded in tillering (Table 5).

Table 5: Mean squares for germination and tillering in combined analysis of variance

Source of variation	Df	Germination %	Number of tillers
Location (L)	2	39158.98**	979371.36**
Genotype (G)	24	235.33**	12678.38**
G×L	48	221.32**	4770.34**
Error	148	113.76	2056.62
Mean	-	40.26	304.44
C.V (%)	-	26.29	14.90
R^2	-	0.85	0.89

**= significant at p≤0.01 *=Significant at p≤0.05

Genotypes performed significantly in germination in the three locations. Twelve genotypes registered better germination than standard varieties. Mean performance of genotypes for germination percentage showed that KEN 04 -1603, KEN 04 -710, KEN 04- 326, and KEN 04 – 2274 were better germinators with a mean range of 45 to 50 %. The combined mean germination for various genotypes ranged from 28.7% to 50 % (Table 6). Fourteen genotypes were superior in tiller production compared to the three check varieties. KEN 04-2765, KEN 04-419, KEN 04-326, KEN 04-710 and KEN 04-1603 were the best five genotypes in tiller production (Table 5).

Table 6: Genotype overall germination performance

Genotype	Mean genotype % germination in three locations
KEN 04 -1603	50.00
KEN 04 – 710	49.56
KEN 04 – 326	48.08
KEN 04 – 2274	45.49
KEN 82 – 493	44.25
KEN 04 -1079	43.51
KEN 04 -1454	42.90
KEN 04 -1809	41.72
KEN 04 -1564	41.23
KEN 04 -2765	40.80
KEN 04 -2349	40.67
KEN 04 – 2010	40.49
EAK 73-335STD	40.30
KEN 04 – 423	40.06
KEN 82-121	39.32
KEN 04 -762	38.76
KEN 04 -100	38.70
KEN 83-737STD	38.14
KEN 04 – 2153	37.84

KEN 04-419	37.65
KEN 04 -1320	37.46
KEN 82 – 472	36.35
D8484STD	34.50
KEN 82 – 601	29.87
KEN 04 – 2192	28.70
Mean Checks	37.64
C.V %	12.70

Table 7: Mean genotype tillering in three locations

Genotype.	Tiller Numbers
KEN 04-2765	359.89
KEN 04-419	355.67
KEN 04-326	352.56
KEN 04-710	346.89
KEN 04-1603	345.67
KEN 04-1320	339.67
KEN 04-100	335.44
KEN 04-1809	329.44
KEN 82-493	320.22
KEN 04-2010	315.89
KEN 04-1454	314.44
KEN 04-2349	307.67
KEN 04-2274	299.78
KEN 04-423	297.22
KEN 83 -737STD	293.44
EAK 73-335STD	292.33
KEN 04-2192	283.44
KEN 82-472	281.44
KEN 04-1564	279.56
KEN 04-1079	278.89

KEN 04-762	274.11
KEN 04-2153	272.78
D8484 STD	272.78
KEN 82-601	267.44
KEN 82-121	194.44
Mean Checks	286.18
C.V %	12.33

4.1.4 Cane quality components.

There were significant ($p \leq 0.05$) differences among the genotypes for sugar yield and its related quality components at Kibos (Table 8).Six genotypes KEN 04-1809, KEN 04-419,KEN 82-601, KEN 04-2192, KEN 82-472 and KEN 82-493 had more sugar than commercial check varieties by 10.7 to 30%.The highest sugar yield of 21.65t $ha^{-1}$was recorded on clone KEN 04-1809 while KEN 04-2153 had the lowest sugar yield of 9.73t ha^{-1}. All the clones in this site were high in brix n indication of high quality. 14 clones gave pol% cane above the mean in this location showing their potential in pol production in Kibos. Mean sugar yield at this site was 15.77 t ha^{-1}. Five genotypes KEN 04-710,KEN 04-1603, KEN 82-121, KEN 04-326, KEN 04-2010,had higher fibre content compared to mean of std varieties 16.97% (Table 8).

Table 8: Sugar yield, Pol %, Brix, Juice, Fibre content of 25 genotype at Kibos

Genotype	Estimated sugar yield t ha^{-1}	Sucrose content (Pol% cane)	Refractometer Brix	Juice purity	Fibre content
KEN 04-1809	21.65	15.11	21.44	89.03	16.98
KEN 83-737STD	20.43	15.14	21.83	91.37	18.72
KEN 04-419	19.92	16.49	22.33	89.07	15.23
KEN 82-601	19.57	16.37	21.81	90.65	16.58
KEN 04-2192	18.92	14.09	21.11	86.80	16.61
KEN 82-472	18.91	15.57	21.50	87.82	15.67
KEN 82-493	18.49	16.86	22.28	90.93	16.78
KEN 04-1079	16.58	16.21	21.74	89.61	16.19
KEN 04-2274	16.09	14.65	21.78	88.65	16.34
EAK 73-335STD	15.77	16.21	21.94	90.55	16.46
KEN 04-2765	15.70	14.38	21.44	85.95	16.15
KEN 04-710	15.66	15.02	21.67	87.07	17.36
KEN 04-1603	15.44	13.32	21.92	85.18	17.80
KEN 04-762	15.14	14.35	20.96	88.46	16.66
KEN 04-2349	15.13	15.39	21.72	88.29	16.49
KEN 04-423	14.65	16.32	21.28	89.25	16.23
KEN 82-121	14.51	14.34	21.67	88.08	17.63

KEN 04-326	14.14	14.72	21.38	90.01	18.51
D 8484STD	14.07	16.21	21.66	90.02	15.16
KEN 04-1320	13.75	14.21	21.44	89.03	15.41
KEN 04-1564	13.61	16.08	22.06	89.71	15.53
KEN 04-1454	12.41	14.06	21.71	87.41	16.06
KEN 04-100	12.09	16.21	21.06	87.67	16.17
KEN 04- 2010	11.81	14.59	21.80	90.22	17.87
KEN 04 -2153	9.73	14.01	21.88	86.45	16.95
Mean	15.77	15.16	21.65	88.69	16.62
LSD ($_{0.05}$)	7.42	1.92	0.79	3.47	1.82
C.V%	28.68	7.71	2.23	2.38	6.67
R^2	0.42	0.57	0.44	0.58	0.56

At Mumias five clones performed better in sugar yields compared to the checks. These genotypes were KEN 04-2010, KEN 04-1079, KEN 04-1603, KEN 82-493 and KEN 04-1809 recorded sugar yields of 16.72, 16.69,15.84.15.35 and 14.90t ha^{-1} more sugar than check varieties with a mean sugar yield of 14.42t ha^{-1}. Sugar yield varied from 6.49 to 16.72 t ha^{-1} with a mean of 11.7 t ha^{-1}(Table 9).

Table 9: Sugar yield, Pol % cane, Brix, Juice, Fibre content of 25 genotype at Mumias

Genotype	Estimated sugar yield t ha^{-1}	Sucrose content (Pol%cane)	Refractometer Brix(^{0})	Juice purity	Fibre content
KEN 04-2010	16.72	11.70	22.25	77.66	13.89
EAK 73-335STD	16.69	13.26	23.39	81.50	14.37
KEN 04-1079	16.69	13.29	23.28	82.24	14.34
KEN 04-1603	15.84	14.92	22.14	81.17	13.96
KEN 83-737STD	15.59	11.24	23.03	77.43	14.86
KEN 82-493	15.35	15.10	23.42	80.22	15.07
KEN 04-1809	14.90	12.11	22.83	80.19	14.19
KEN 04-2765	13.99	12.31	22.00	83.10	14.91
KEN 04-762	13.42	9.13	22.78	73.98	14.50
KEN 04-710	13.13	11.78	23.47	74.95	14.01
KEN 04-1320	12.41	11.82	21.86	78.09	14.20
KEN 04-419	11.90	12.24	22.19	80.21	13.76
KEN 04-326	11.65	12.16	21.61	81.67	14.16
D 8484STD	10.99	13.58	23.81	78.20	14.78
KEN 04-100	10.28	11.20	21.97	73.82	13.64
KEN 04-423	10.16	12.13	22.11	79.59	14.19

KEN 04-2349	9.76	11.86	23.36	77.07	14.42
KEN 82-472	9.51	12.93	22.58	80.35	15.03
KEN 04-1454	9.40	12.57	22.19	78.73	14.64
KEN 04-2192	8.39	8.79	22.36	76.06	14.30
KEN 82-121	8.39	12.70	23.72	77.95	15.33
KEN 04-2274	8.08	11.38	21.39	75.14	14.61
KEN 04-2153	7.59	12.56	23.58	81.75	14.42
KEN 04-1564	7.41	13.24	20.81	78.19	14.23
KEN 82-601	6.49	8.55	23.75	76.82	14.75
Mean	11.79	12.10	22.64	78.64	14.42
LSD ($_{0.05}$)	7.57	3.32	1.45	8.04	1.73
C.V%	39.09	16.73	3.91	6.23	7.29
R^2	0.46	0.56	0.57	0.51	0.22

Genotypes differed significantly ($p \leq 0.05$) in sugar yields at South Nyanza (Table 10). Clones KEN82-601 and KEN 04-1809 with 18.26 and 18.05 t ha^{-1} of sugar were better than the std varieties with a mean sugar yield of 17.53 t ha^{-1}. Estimated sugar yield ranged from 10.87 to 18.26 t ha^{-1} with an average of 15.58 t ha^{-1}.

Table 10: Sugar yield, Pol % cane, Brix and Fibre content of 25 genotypes at South Nyanza

Genotype	Estimated Sugar yield t ha^{-1}	Sucrose content (pol% cane)	Refractometer Brix(^{0})	Juice Purity	Fibre content
EAK 73-335STD	18.91	14.46	21.30	90.63	15.23
KEN 82-601	18.26	13.65	21.44	88.97	15.20
KEN 04-1809	18.05	13.92	21.52	89.89	15.27
D8484STD	17.43	14.34	21.32	89.72	15.33
KEN 04-2349	17.02	13.69	22.24	88.27	14.97
KEN 04-423	16.81	13.30	21.98	87.88	15.17
KEN 04-1079	16.47	13.49	21.66	88.46	15.17
KEN 83-737STD	16.26	13.52	21.24	89.40	15.50
KEN 04-710	16.14	13.25	21.12	89.43	15.63
KEN 04-2274	16.10	14.23	21.36	89.01	15.30
KEN 04-419	16.07	13.56	21.20	88.20	15.27
KEN 04-1603	16.04	13.65	20.22	88.64	15.27
KEN 04-1564	16.04	13.33	21.51	88.53	15.20
KEN 04-326	15.48	13.69	21.14	88.36	15.17
KEN 04-2010	15.44	13.66	21.70	88.71	15.20
KEN 04-2153	14.92	13.63	22.13	88.72	15.43

KEN 82-472	14.91	13.03	21.98	88.49	15.23
KEN 04-100	14.74	13.52	21.38	88.40	15.13
KEN 04-762	14.51	13.26	22.12	88.99	15.30
KEN 82-121	14.46	13.66	21.74	88.43	15.17
KEN 04-2192	14.37	13.64	21.18	88.47	15.17
KEN 04-1320	13.75	13.56	21.62	88.18	15.60
KEN 82-493	13.37	14.12	21.39	89.01	15.07
KEN 04-1454	13.07	13.65	21.33	87.87	15.40
KEN 04-2765	10.87	13.33	21.23	88.41	15.23
Mean	15.58	13.65	21.48	88.76	15.26
LSD ($_{0.05}$)	5.01	0.82	0.76	1.70	0.49
C.V%	19.57	3.66	2.15	1.17	1.97
R^2	0.37	0.46	0.56	0.37	0.35

In the combined ANOVA genotypes exhibited significant ($P \leq 0.01$) and ($P \leq 0.05$) differences in the following traits (hand refractometer brix, pol% cane, and sugar yield). Effects due to locations were significant ($P \leq 0.01$) in all quality traits studied. Genotype × location (G×L) interaction was significant ($P \leq 0.01$) for hand refractometer brix only. Coefficient of determination ranged ($R^2=0.49$) for sugar yield to high of ($R^2=0.75$) in juice purity (Table 11).

Table 11: Mean square and their significance on quality parameters of 25 genotypes evaluated at Kibos, Sony and Mumias

Source of variation	Df	Juice purity (%)	Fibre content (%)	Sucrose content (Pol%cane)	Brix(^{0})	Sugar yield (t ha^{-1})
Location (L)	2	2542.38**	92.44**	176.46**	28.97**	377.95**
Genotype (G)	24	10.26	1.12	4.59*	1.16**.	29.84*
Replication within location(R)	2	69.58	2.81	2.22	0.67	10.33
G×L	48	9.70	1.09	3.09	0.88**	19.09
Error	148	13.69	0.84	2.47	0.40	17.71
Mean	-	85.37	15.44	13.64	21.93	14.38
C.V (%)	-	4.33	5.93	11.52	2.90	29.27
R^2	-	0.75	0.69	0.63	0.68	0.49

**= significant at p≤0.01 *=Significant at p≤0.05

4.4 Analysis of variance for cane yield components

The effects of location were significant (p≤0.05) for cane yield and stalk diameter and highly significant (P≤0.01) for height, number of milleable stalks and number of internodes per stalk (Table 12). Genotypes also differed significantly in all the traits (p≤0.05) and genotype × location interaction was significant for stalk diameter, and milleable stalks. Coefficient of determination ranged from (0.46%) for cane yield in t ha^{-1} to high of (0.71%) for number of milleable cane.

Table 12: Mean squares and their significance on cane yield components of 25 genotypes evaluated at Kibos, South Nyanza and Mumias

Source of variation	Df	Cane yield t ha^{-1}	Stalk diameter (cm)	Height (cm)	Number of milleable stalks	Number of internodes
Location (L)	2	5299.44*	0.31*	8924.95**	168941.99**	297.16**
Genotype (G)	24	1575.49*	0.10*	1632.89*	9006.73**	16.25*
Replications within location(R)	2	722.49	0.09	1215.53	1144.96	0.62
G×L	48	980.50	0.10*	999.05	5093.58**	9.82
Error	148	764.66	0.05	758.68	2221.89	8.82
Mean	-	105.10	2.44	229.93	245.36	24.69
C.V (%)	-	26.31	8.79	11.98	19.21	12.03
R^2	-	0.46	0.54	0.49	0.71	0.53

**= significant at p≤0.01 *=Significant at p≤0.05

4.5 Correlations among traits associated with cane and sugar yield

The components associated with cane yield are stalk height, stalk weight, and stalk diameter and number of milleable stalks. Cane yield was significantly correlated to the number of milleable stalks and positively associated with stalk height, number of internodes, pol% cane and juice purity but significant negative correlation on brix and stalk diameter (Table 13) Number of milleable stalks was positively correlated with stalk

height, pol % cane and purity but had a negative correlation with stalk diameter, brix and fibre and stalk height. Number of internodes had a significant positive correlation with stalk height but positively associated with all the traits. Associations between pol % cane and purity were highly significant, with pol% cane registering a positive correlation with brix. Fibre % cane had significant positive correlation with juice purity while stalk diameter correlated with brix and heath but registered weak negative association with pol % cane and purity.

Table 13: Simple correlations for cane yield and quality components in three locations

Trait	Brix(^{0})	Juice Purity	Fibre	Pol% cane	Stalk diameter (cm)	Stalk height (cm)	Number of milleable stalks	Cane yield t ha^{-1}
Juice Purity	-.04							
Fibre	-.09	0.14						
Pol % cane	0.08	0.55**	-.09					
Stalk diameter	0.12	-.24*	-.18	-.27*				
Stalk height	0.00	-.01	-.010	-.06	0.10			
Number of milleable stalks	-.27*	0.06	-.017	0.00	-.230*	0.01		
Cane yield t ha^{-1}	-.27*	0.07	-.004	0.01	-.21	0.06	0.99**	
No. of internodes	0.13	0.18	0.16	0.19	0.02	0.63**	0.11	0.17

4.6 Performance of genotypes in cane yield and its components in the 3 locations

Genotypes in South Nyanza Awendo performed differently in cane yield and other yield related characters (Table 14). Genotype KEN 82-601 had the highest cane yields of (7.70%) of the check varieties followed by KEN 04-1603 (4.32%) and KEN 04-423 (2.18%) respectively thus better than the mean of check varieties. Seven test genotypes were superior in stalk diameter to the check varieties while eleven produced more of milleable stalks as compared to the checks varieties. The highest number of internodes was recorded on genotype KEN 82-121, KEN 04-1454 and KEN 04-710. The three genotypes produced internodes (15.98%) better than check cultivars. The cane yield ranged from 80.79 to 133.97 t ha^{-1} with a mean of 114.14 t ha^{-1}.

Cane yield for the genotypes was better than the check cultivars at Kibos (Table 15).Genotypes KEN 04 -1809, KEN 04 -2192,KEN 82- 472, KEN 04-419 and KEN04-1809 outperformed all the three check varieties in yields by 35.12%, 28.27%. 25.30 %, 13.80 % and 13.74 % respectively. Mean cane yield ranged from 67.36 to144.17 t ha^{-1} with an overall site mean of 103.66 t ha^{-1}. Genotype 04-2192 exhibited high yield and stalk population at Kibos.

Genotype yield performance in Mumias was different in the yield attributes measured **(**Table 16). Three genotypes KEN 04– 762, (146.45t ha) KEN 04-2010, (143.10t ha), KEN 04-1809 (123.82t ha) and KEN 04-1079(116.77t ha) were superior in yields to checks (116.59t ha) The highest number of milleable stalks was recorded on genotype KEN 04-2765. The genotype produced 45.5% more milleable cane than the standard

varieties. Highest stalk length (283.61cm) was observed on genotype KEN 04-2010.Cane yield at Mumias was in the range of 53.11 to 146.45 t $ha^{-1}$with a mean site yield of 97.51. Mean cane yield and agronomic parameters were lower at Mumias than at Sony and Kibos. Overall yields of genotypes were 47.75% and 6.30% more in cane yield at Sony and Kibos than Mumias. Outstanding genotypes in cane yield across the three locations were KEN 04-1809, KEN 04-762, and KEN 04 -1603 (Table 17).

Table 14 : Cane yield, stalk diameter, stalk height, number of internodes and number of milleable stalks for 25 genotype evaluated at South Nyanza Awendo in plant crop

Genotype	Cane yield (t ha^{-1})	Stalk diameter (cm)	Stalk height (cm)	Number of milleable stalks	Number of internodes $Stalk^{-1}$
KEN 82-601	133.97	2.54	245.11	262.33	22.17
EAK 73-335STD	130.81	2.56	253.17	247.67	23.56
KEN 04-1809	129.67	2.49	222.17	310.33	24.00
KEN 04-423	127.01	2.31	245.61	329.67	26.67
KEN 04-2349	124.28	2.41	230.28	308.67	25.72
KEN 04-1079	121.90	2.43	242.83	262.33	26.61
D 8484STD	121.81	2.95	237.72	241.00	23.67
KEN 04-710	121.44	2.72	236.94	221.33	27.06
KEN 04-1564	120.93	2.37	210.39	325.33	21.72
KEN 83-737STD	120.26	2.27	256.06	340.00	23.33
KEN 04-419	118.90	2.41	234.22	312.67	25.67
KEN 04-1603	117.26	2.42	227.72	278.67	23.39
KEN 82-472	114.53	2.71	221.78	238.33	23.39
KEN 04-326	113.67	2.21	204.33	300.00	21.89

KEN 04-2010	112.99	2.45	258.67	308.00	25.44
KEN 04-2274	112.83	2.35	230.39	301.00	23.94
KEN 04-2153	109.56	2.78	208.61	230.33	22.72
KEN 04-762	109.26	2.16	219.61	360.33	23.11
KEN 04-100	108.94	2.73	222.39	256.00	23.89
KEN 82-121	105.72	2.69	236.83	242.00	27.50
KEN 04-2192	105.19	2.53	224.06	249.67	23.17
KEN 04-1320	101.68	2.76	213.06	265.67	23.22
KEN 04-1454	95.13	2.28	197.28	291.33	27.28
KEN 82-493	94.83	2.44	220.78	237.67	26.44
KEN 04-2765	80.79	2.68	215.22	178.00	23.72
Mean	114.14	2.51	228.61	275.93	24.37
LSD ($_{0.05}$)	35.82	0.39	41.82	92.24	4.11
C.V (%)	19.12	9.43	11.14	20.36	10.28
R^2	0.37	0.54	0.38	0.48	0.44

Table 15: Cane yield, stalk diameter, stalk height, number of internodes and number of milleable stalks for 25 genotype evaluated at Kibos in plant crop

Genotype	Cane yield (t ha^{-1})	Stalk diameter (cm)	Stalk height (cm)	Number of milleable stalks	Number of internodes $Stalk^{-1}$
KEN 04-1809	144.17	2.28	234.94	236.00	23.22
KEN 83-737STD	136.86	2.47	253.33	209.67	22.83
KEN 04-2192	133.80	2.50	258.28	279.00	24.89
KEN 82-472	121.49	2.54	234.78	177.67	24.00
KEN 04-419	121.35	2.33	246.78	187.67	24.00
KEN 82-601	119.93	2.40	257.39	151.00	23.44
KEN 04-1603	116.06	2.54	233.50	250.00	23.83
KEN 82-493	110.26	2.71	270.50	150.00	26.17
KEN 04-2274	108.73	2.60	232.94	176.33	19.56
KEN 04-2765	108.70	2.25	234.06	187.33	24.00
KEN 04-710	104.95	2.41	218.39	191.00	19.17
KEN 04-762	103.30	2.40	240.11	191.67	21.00
KEN 82-121	100.57	2.43	232.06	129.33	24.39
KEN 04-2349	99.53	2.59	246.28	173.00	24.83
KEN 04-1079	99.17	2.64	231.61	190.67	21.72
KEN 04-1320	97.10	2.40	236.39	191.33	21.17
EAK 73-335STD	95.95	2.31	209.83	199.33	22.06

KEN 04-326	93.70	2.61	266.00	207.33	22.67
KEN 04-423	89.81	2.32	224.33	181.67	22.39
KEN 04-1454	87.92	2.60	262.11	185.33	21.33
D8484STD	87.26	2.33	223.28	101.33	24.44
KEN 04-1564	83.92	2.42	239.50	241.00	22.00
KEN 04-2010	80.22	2.26	256.94	193.33	23.72
KEN 04-100	79.32	2.53	253.28	232.00	23.33
KEN 04-2153	67.36	2.39	239.22	154.00	22.83
Mean	103.66	2.45	241.43	190.68	22.88
LSD ($_{0.05}$)	46.02	0.40	45.22	53.51	4.36
C.V (%)	27.04	9.96	11.41	17.09	11.61
R^2	0.42	0.31	0.40	0.68	0.44

Table 16: Cane yield, stalk diameter, stalk height, number of internodes and number of milleable stalks for 25 genotype evaluated at Kibos in plant crop

Genotype	Cane yield (t ha^{-1})	Stalk diameter (cm)	Stalk height (cm)	Number of milleable stalks	Number of internodes $Stalk^{-1}$
KEN 04-762STD	146.45	2.62	248.28	282.33	28.56
KEN 83-737	143.10	2.22	267.56	264.67	30.06
KEN 04-2010	143.02	2.56	283.61	264.33	29.50
EAK 73-335STD	123.82	2.57	202.44	312.33	24.44
KEN 04-1809	123.13	2.35	249.83	287.00	27.56
KEN 04-1079	116.77	2.35	224.33	234.67	29.00
KEN 04-2765	112.10	2.14	218.39	394.67	26.39
KEN 04-710	111.14	2.31	247.94	257.33	28.78
KEN 04-1603	105.10	2.39	211.56	298.67	27.56
KEN 82-493	103.83	2.31	214.00	250.67	32.94
KEN 04-1320	102.80	2.20	202.28	358.00	25.89
KEN 04-419	97.86	2.39	213.72	296.00	24.89
KEN 04-2192	96.36	2.30	210.11	277.67	24.17
KEN 04-326	96.11	1.96	232.33	335.33	26.78
KEN 04-100	91.98	2.42	196.94	278.67	26.72

D8484STD	82.85	2.87	233.06	179.33	25.94
KEN 04-423	82.44	2.34	237.61	288.00	23.44
KEN 04-2349	82.41	2.20	215.56	249.33	28.89
KEN 04-2274	75.51	2.29	207.89	264.67	24.94
KEN 82-601	74.83	2.78	238.17	145.33	27.56
KEN 04-1564	53.11	2.28	184.56	289.00	25.61
KEN 82-472	72.99	2.65	190.67	235.67	23.83
KEN 82-121	65.95	2.40	205.78	162.33	29.67
KEN 04-2153	60.67	2.26	176.39	298.33	22.22
KEN 04-1564	53.11	2.28	184.56	232.00	25.61
Mean	97.51	2.38	219.74	269.45	26.82
LSD ($_{0.05}$)	52.07	0.24	46.90	78.89	5.12
C.V (%)	32.52	6.16	13.00	17.84	11.63
R^2	0.51	0.75	0.57	0.68	0.55

Table 17: Genotype overall performance cane yield across locations

Genotype	Mean cane yield in t ha^{-1}
KEN 83-737STD	133.41
KEN 04-1809	132.32
KEN 04-762	119.67
EAK 73-335STD	116.86
KEN 04-1603	112.81
KEN 04-419	112.71
KEN 04-1079	112.61
KEN 04-710	112.51
KEN 04-2010	112.12
KEN 04-2192	111.79
KEN 82-601	109.58
KEN 82-472	103.00
KEN 82-493	102.98
KEN 04-2349	102.07
KEN 04-326	101.16
KEN 04-2765	100.53
KEN 04-1320	100.53
KEN 04-423	99.75
KEN 04-2274	99.03
D8484STD	97.31

KEN 04-100	93.41
KEN 82-121	90.75
KEN 04-1564	85.99
KEN 04-1454	85.47
KEN 04-2153	79.19
Mean cane yield checks (t ha^{-1})	**115.86**
C.V %	**12.59**

CHAPTER FIVE

DISCUSSION

5.1 Effect of environment on qualitative components

The significant differences between genotypes in pol, brix, and sugar yields noted in this study indicated variability among genotypes hence a possibility of genetic improvement in most of the quality traits through selection (Punia, 1982; Khan *et al*., 2014).The significant genotype × location interactions for brix indicated that the performance of genotypes for this trait is highly influenced by locations. This interaction was as a result of change in genotype ranking across the locations. This further suggests that mean performance of genotypes could be used in selecting of superior genotypes on the basis of these traits. This gives more emphasis that at the preliminary stage of clone evaluation, multi-location testing continues to be more sufficient (Chang, 1996; Khan *et al.,* 2004). Jamoza, (2011) reported significant G×L interactions for sucrose content, fibre and sugar yields but non-significant interactions for brix and juice purity suggesting that performance of the clones was the same for the two traits in the three locations. The results obtained (Table 11) of this study contradicts Jamoza, (2011) and this implies that the environment and other factors such as crop management will influence performance of certain traits in sugarcane. Crop cycles and seasons have shown to create different interactions thus Jamoza, (2011) tested in two crop cycles which could have contributed to the findings. Environments also play a role in creating variation in the performance of the traits hence Nzoia and South Nyanza sugar zones lie in different localities with

different aspects of weather and all these factors together with different management skills could have contributed to variances in the two studies resulting from the interactions. Sugarcane varieties also differ in their ability to respond to different environments and this is evident from the changes in the relative rank performance in the quality attributes from one location to another.

5.2 Correlations among quality and cane yield traits

Simple correlations performed detected associations in all the quality traits measured mainly pol% cane, purity, fibre and brix (Table 13). These results are in line with Khan *et al*., (2001) who found that purity was positively associated with sucrose and that brix value and sucrose content was positive and significant. Similar results were presented by Chang *et al*., (1996) where correlations between commercial cane sugar, purity and sucrose were positive. Refractometric brix is used by breeders as an indicator of sucrose content. The results there suggests that it is possible to estimate amount of sucrose in a given genotype based on one or two traits since a high level of purity is an indicator of high sucrose content. Refractometric brix can therefore be used in the field as an indicator of cane maturity. Mamet *et al*. (1999) concluded that the reliability of field brix as a predictor of sucrose content depends upon the method applied and time of its sampling. Brix is negatively correlated to fibre % cane as the higher the fibre the lower the brix levels in a sugarcane crop. Pol and purity have a strong and positive relationship. The study results suggest that in order to enhance the quality traits in sugarcane effective strategies for selection should be based on multi-location testing to identify superior lines for each individual site on the basis of the trait under the study.

Correlations among phenotypic traits may indicate biological processes that are of considerable interest and can be the result of genetic, functional and physiological or developmental nature (Soomoro *et al*., 2006; Ulloa, 2006). These results are in line with Khan *et al.,* (2001) who found that purity was positively associated with sucrose and that brix value and sucrose content was positive and significant. Similar results were presented by Chang *et al.,* (1996) whereby correlations between commercial cane sugar, purity and sucrose were positive. Rostron *et al.,* (1971) found that season had only a small effect on sucrose content, expressed on either fresh or dry weight basis, after 56 weeks of age. Varieties of the same age may be physiologically different causing them to mature at different ages. In this study all the twenty two clones used could have differed in maturation periods thus some varieties may be disadvantaged if harvested at the same age as this leads to loss of sucrose. This implies that when testing for sucrose content the early maturing clones should be clearly identified and established separately from the late maturing varieties in the final testing phase of variety evaluation

5.3 Genotypic performance on sugar yield

Sugar yield and the associated quality traits were highest in Kibos and lowest at Mumias except for hand refractometer brix. Genotypes KEN 04-1809, KEN 04-419, KEN 82-601, KEN 04-2192, KEN 82-472,and KEN 82-493 performed well specifically at Kibos in sugar yields (Table 8).The following genotypes, KEN 04-2010, KEN 04-1079, KEN 04-1603,and KEN 82-493performed exceptionally well in Mumias zone and are suitable for production in this location (Table 9) while genotypes KEN 82-601, KEN 04-1809, KEN

04-2349, KEN 04-423, and KEN 04-1079 may be recommended for cultivation in South Nyanza Awendo for high sugar content(Table10). Mean values for the sugar yield related traits mainly pol, purity and fibre were highest in Kibos, South Nyanza Awendo and Mumias respectively. This indicates that the environmental factors in Kibos were more favorable for sugarcane sucrose production compared to the two other locations (Appendix 1 and 2). This further emphasizes on the importance of multi-location testing of clones prior to selection for specific attributes in these locations. Testing of genotypes in a wide range of environments offers them a chance to express their full potential in various traits under test. Sugar cane juice quality is influenced by several factors namely nutrition (Gascho *et al.,* 1986) climate (Haltam and Pazir, 1989) diseases and variety (Habib *et al*., 1992). Genotype KEN 82-493 was outstanding in the three environments in terms of high pol production while six genotypes KEN 04-1809, KEN 04-1603, KEN 04-1079, KEN 04-419, KEN04-2010, and KEN 04-2192 performed well both in cane yield and sugar yield. These genotypes can be considered for utilization for both yield and sugar content. Differences in the sugar yield performance can be attributed to variations in the three locations in terms of soils, moisture, temperature and also crop management practices.

Sugarcane production practices in the Mumias sugar zone have led to serious deterioration of soil physical and chemical properties. This zone contributes 50-60% of national sugar production, mean sugarcane yields declined from 110 in 1996 to 55 t ha^{-1} in 2012 (KSB, 2012). Continuous uses of artificial fertilizers have been linked with increased vegetative growth and biomass production in sugarcane at the expense of

sucrose. Low yield productivity in Mumias would have resulted from the continuous use of ammonium based fertilizers, lack of crop rotation, and high precipitation. These factors are believed to have lowered pH values to 4.5-5.4 over the years (Mutonyi, 2014). This agrees with Jaetzold *et al.,* (2005) that soil productivity in the densely populated western province is low and on the decline. Deficiencies of N, P and K are widespread in Western Kenya leading to low a decline in crop yields.

High sugar yields in Kibos could have resulted from high temperatures (20^0-27^0C) accompanied with dry sunny conditions hence promoting sugar accumulation. Evenly distributed rainfall with deep fertile well drained soils alluvial, clay and black cotton soils together with dry and sunny harvesting enhances maximum accumulation of sucrose in sugarcane. Good fertile soils, crop husbandry practices accompanied by favourable weather could be the key contributing factors to good sugar yields that were attained at South Nyanza Awendo.

5.4 Correlations among quality and cane yield traits

Simple correlations performed detected associations in all the quality traits measured mainly pol% cane, purity, fibre and brix (Table 13). These results are in line with Khan *et al*., (2001) who found that purity was positively associated with sucrose and that brix value and sucrose content was positive and significant. Similar results were presented by Chang *et al*., (1996) where correlations between commercial cane sugar, purity and sucrose were positive. Refractometric brix is used by breeders as an indicator of sucrose content. The results there suggests that it is possible to estimate amount of sucrose in a

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used could have differed in maturation periods thus some varieties may be disadvantaged if harvested at the same age as this leads to loss of sucrose. This implies that when testing for sucrose content the early maturing clones should be clearly identified and established separately from the late maturing varieties in the final testing phase of variety evaluation.

5.5 Implication of environment on quality

Significant differences were detected in locations for sucrose content and sugar yields indicating that sites were different in these traits (Table 11). The differences environmental differences within the three sites (Appendix 1 and 2) contributed significantly to the differences in the production of sucrose and sugar yields. These sites were influenced by soils, temperatures, rainfall and to some extent management and these contributed to variations in the sucrose content achieved. Therefore testing of genotypes across locations was more prudent than testing across seasons. The significant values for genotypes effect for both sucrose content and sugar yields indicated that genotypic differences were detected in the study and that selection of superior genotypes for both traits could be achieved effectively in the respective locations based on the performance of the clones (Gilbert *et al.,* 2006).

5.6 Combined analysis of variance for cane yield

Sugarcane yield is determined by various factors namely soil, genotype, management and prevailing weather conditions. A combination of these factors together with cane stalk number and weight contribute greatly to the yields of sugarcane. Jamoza, (2011) reported that stalk diameter, number of milleable cane and stalk height are by far the main yield

components in sugarcane. The performance of genotypes in this study was not stable some yield and quality traits in the three locations. From the results it was evident that Cane yield, stalk diameter, stalk height and number of milleable stalks were influenced by location and genotypes. Significant differences were observed in all the yield attributes of 25 genotypes (Table 12). This indicates that genotypes varied greatly in performance in the three locations. Locations were also highly significant in all the yield attributes tested (Table 12).This also suggests that the genotypes were highly variable in their performance hence specific genotypes can be recommended for each location after thorough testing. The differences in G×E interaction is an indication that the three sites were located in different zones and that variations in rainfall, soils, mineral content and air temperature may contribute to G × E interactions. This is in agreement with (Gilbert *et al*., 2006).G × L interactions were significant for two traits, girth and number of milleable cane while the other parameters were non-significant.

Significant correlations were observed on key yield components with an exception of stalk diameter which had a negative correlation with cane yield. This implied that these traits were more important and can be used in selection criteria for yield improvement in sugarcane. The results were in agreement with Sanghera *et al*., (2015) that cane yield was significantly and positively correlated to number of milleable stalks, stalk length, single cane weight, and germination at 45 days after planting. Jamoza *et al*., (2014) reported significant differences among genotypes for cane yield and related traits. These results indicated that improvement in any of these three characters may result in positive response of cane yield. Ishaq *et al*., (2002) found that stalk weight, height, number of

milleable stalks, leaf area were the major traits contributing to cane and sugar yield. Stem diameter was found to be an important component of yield since it was positively correlated with stalk weight, height and leaf area. A negative correlation between stalk diameter and cane yield indicates that these two traits were independent hence an increase in one of the traits will automatically lead to a reduction in the other hence when selecting for the two it can be done independently. Hogarth *et al.,* (1990) found positive correlation (0.81) between stalk height and cane yield whereas Hooda *et al*., (1979) reported significant positive correlations between stalk diameter and clump yield.

Results on association of quality and yield components indicated that girth had a significant association with purity and pol suggesting that an increase in girth resulted in an increase in the two parameters. Number of milleable stalks had a negative association with all other traits except cane yield, girth and brix. The results indicated that improvement in this trait could lead to a resultant increment of the three traits. This study suggests that pol % cane can be enhanced by selecting clones that have more thick stalks. Therefore selection strategy based on thick and high number of milleable cane stalks could lead to improvement in yield and quality in sugarcane.

The significant genotype × location interactions for cane and sugar yields suggest that testing of genotypes should be done in more locations and recommendations done based on results from specific test regions. Performance of clones based on cane yields was varied in all three locations in plant crop. KEN 82-601, KEN04-1809, KEN04-423, KEN04-2349, KEN04-1079, and KEN 04-710 were the most outstanding genotypes in

cane yield in South Nyanza Awendo(Table 14). In Kibos, superior genotypes in cane yield were KEN 04-326, KEN 04-710, KEN 04-1079 and KEN 04-1809 (Table 15). In Mumias, clones KEN 04-762, KEN04-2010, KEN 04-1809, KEN04-1079, and KEN04-2765 were better in cane yield compared to the checks (Table 16).Overall cane yield performance indicated two genotypes KEN 04-1809 and KEN 04-762 produced higher yield than the check varieties by 14.2 and 3.2 % respectively. Five other genotypes KEN 04-1603,KEN 04-419,KEN04-1079,KEN04-710 and KEN 04-2010 had similar yield of 112 t ha^{-1}(Table 17).Variations in performance of the genotypes could be as a result of differences in the three production areas in terms of soils, rainfall patterns and amounts and temperatures. In cane yield and related traits, performance was high in South Nyanza Awendo than Kibos and Mumias. This indicates that the environment in South Nyanza was more favorable for sugarcane yield production compared to the other two environments.

The high significance values for location effects of cane yield across locations compared to sucrose content indicate larger variability in cane yield across locations compared to sucrose content and therefore sucrose content was more stable across locations. Generally yield in cane is more sensitive to changes in environments (Mirzawan *et al*., 1994).

For quantitatively inherited traits such as cane and sugar yields, genotype values and their relative rankings can change from one environment to another and this suggests the effect of environment on sugarcane productivity (Kang, 2002).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

1. This study detected significant genotypic differences in pol % cane, brix and sugar yield in each of the three locations.
2. Cane yield components were significant among locations and genotypes an indication that locations elicited different responses from varieties or clones responded differently in each location.
3. Under conditions of this study 7 genotypes are recommended to have good potential for production in sugar and cane yields.

6.2 Recommendations

1. Evaluation of clones for yield and quality should be conducted in plant crop in many locations rather than crop years.
2. A greater number of sites needs to be included in further so as to come up with distinct genotypes for specific agro-ecological zones.
3. Further research work to be undertaken on the 7 genotypes identified in this study as they have good potential for production of sugar and cane yields.

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APPENDICES

Appendix 1: Rainfall patterns in (mm) between July - September 2012 for Mumias, Kibos and South Nyanza Awendo

	Mumias			Kibos			South Nyanza Awendo		
Date	**Jul**	**Aug**	**Sept**	**Jul**	**Aug**	**Sept**	**Jul**	**Aug**	**Sept**
1	0.0	3.2	34.0	0.0	1.3	0.0	0.0	7.8	0.5
2	25.4	13.5	16.7	0.0	0.8	0.0	0.0	2.7	4.5
3	0.0	0.0	0.8	0.0	0.0	3.6	0.0	0.0	0.0
4	0.0	0.0	1.2	0.0	0.0	0.6	0.0	0.0	2.5
5	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	2.0
6	0.0	0.1	11.0	0.0	23.3	2.4	0.0	0.0	26.2
7	0.0	0.0	8.7	0.0	0.0	4.2	0.0	0.0	1.0
8	0.0	6.1	1.5	0.0	0.0	35.1	0.0	13.0	4.0
9	0.0	12.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
10	63.8	0.0	15.4	0.0	0.0	0.5	0.0	0.0	4.5
11	0.0	5.5	6.3	0.0	1.3	0.0	0.0	11.0	3.0
12	10.6	0.5	1.5	0.0	7.0	0.0	0.0	0.0	13.5
13	3.3	0.0	21.7	1.6	0.0	0.0	0.0	0.0	7.0
14	0.0	0.0	1.5	0.0	0.0	2.2	3.0	0.0	24.0
15	6.5	0.0	3.1	0.0	0.0	2.5	0.0	0.0	2.2
16	0.0	0.0	1.7	0.0	0.0	0.0	4.2	0.0	0.0

17	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
18	0.0	0.3	8.5	8.9	0.4	0.0	0.0	2.5	27.5
19	0.0	36.7	3.2	1.7	4.2	4.2	0.0	6.0	0.0
20	0.0	2.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0	2.0
22	0.0	14.5	0.0	10.5	0.0	0.0	8.2	1.1	4.0
23	14.9	36.2	0.2	18.2	0.0	0.0	0.5	0.0	36.3
24	4.8	0.0	1.2	0.0	0.0	4.8	0.0	0.0	6.0
25	0.0	0.9	0.0	5.6	0.0	29.3	0.0	0.7	0.0
26	0.0	0.0	16.8	0.0	11.0	15.8	0.0	15.5	7.7
27	1.0	8.4	26.8	4.3	1.2	16.2	0.0	1.5	1.0
28	0.2	0.0	40.8	0.0	1.2	8.3	0.0	0.6	0.0
29	0.0	0.3	0.0	0.0	0.0	7.9	0.0	0.0	0.0
30	0.0	28.0	0.0	0.0	9.6	0.0	0.0	9.0	0.0
31	9.6	23.9	-	0.0	8.0	-	2.5	0.0	-
Total	**140.3**	**192.9**	**223.4**	**64.0**	**69.3**	**141.20**	**18.4**	**71.4**	**201.4**
Mean	**4.5**	**6.2**	**7.44**	**2.1**	**2.3**	**4.7**	**0.6**	**2.4**	**6.7**

Appendix 2: Locational temperature data Kibos, South Nyanza, andMumias

SITE:KIBOS

	Jul-12			Aug-12			Sep-12		
Date	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
1	27.2	14.9	21.1	26.0	15.5	20.8	29.2	14.5	21.9
2	28.0	16.2	22.1	28.2	16.6	22.4	29.5	17.4	23.5
3	27.0	15.2	21.1	29.5	17.6	23.6	27.5	15.4	21.5
4	28.0	15.4	21.7	29.2	17.2	23.2	29.0	17.8	23.4
5	27.6	17.0	22.3	27.2	17.9	22.6	26.0	18.0	22.0
6	27.0	17.5	22.3	29.0	16.5	22.8	29.0	16.4	22.7
7	28.0	14.2	21.1	30.6	18.0	24.3	29.2	14.7	22.0
8	27.8	14.2	21.0	26.6	17.5	22.1	27.5	16.8	22.2
9	29.5	15.0	22.3	27.5	14.6	21.1	26.5	14.5	20.5
10	28.2	15.8	22.0	28.5	16.0	22.3	28.6	16.6	22.6
11	27.2	15.5	21.4	29.0	14.0	21.5	29.2	17.4	23.3
12	28.6	16.5	22.6	28.0	14.9	21.5	29.0	16.5	22.8
13	29.2	16.8	23.0	28.4	15.4	21.9	29.0	16.5	22.8
14	28.5	15.0	21.8	28.6	16.0	22.3	29.6	16.2	22.9
15	28.6	16.4	22.5	29.5	16.8	23.2	29.0	17.2	23.1
16	28.5	15.0	21.8	29.0	18.5	23.8	28.8	17.1	23.0
17	28.6	16.5	22.6	28.5	18.0	23.3	30.2	15.2	22.7
18	29.2	18.2	23.7	29.0	16.7	22.9	29.5	14.8	22.2
19	25.6	17.4	21.5	29.0	17.1	23.1	30.2	15.5	22.9

20	28.0	15.3	15.3	27.0	15.5	15.3	30.5	15.5	23.0
21	28.5	17.0	21.9	29.6	13.2	22.6	30.5	15.0	22.8
22	29.7	17.0	23.4	29.5	17.5	21.4	31.0	16.3	23.7
23	29.5	17.2	23.4	30.5	15.5	23.0	30.5	16.6	23.6
24	25.0	17.2	21.1	29.5	15.0	22.3	30.5	15.2	22.9
25	29.0	18.0	23.5	30.6	16.5	23.6	29.6	16.5	23.1
26	25.6	15.5	20.6	29.4	16.0	22.7	29.6	16.5	23.1
27	28.0	17.8	22.9	29.2	16.2	22.7	29.8	16.0	22.9
28	26.2	17.8	22.0	28.8	15.8	22.3	29.5	16.5	23.0
29	28.0	18.2	23.1	29.2	15.5	22.4	30.2	16.5	23.4
30	27.5	16.6	22.1	24.2	17.5	20.9	30.5	15.5	23.0
31	29.5	18.0	23.8	27.8	15.5	21.7			

SITE:MUMIAS

	Jul-12			Aug-12			Sep-12		
Date	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
1	27.0	17.0	22.0	28.0	15.0	21.5	30.0	14.0	22.0
2	27.0	16.0	21.5	27.0	15.0	21.0	30.4	14.3	22.4
3	27.0	17.0	22.0	28.0	15.0	21.5	30.0	14.3	22.2
4	27.0	15.0	21.0	28.0	15.0	21.5	30.0	14.0	22.0
5	28.0	17.0	22.5	29.0	15.0	22.0	30.0	15.0	22.5
6	26.0	17.0	21.5	29.1	15.0	22.1	30.0	15.0	22.5
7	27.0	16.0	21.5	29.0	15.0	22.0	30.0	15.0	22.5
8	27.0	16.0	21.5	28.0	16.0	22.0	30.0	15.0	22.5
9	28.0	16.0	22.0	29.7	14.8	22.3	27.6	15.0	21.3
10	27.0	16.0	21.5	29.7	14.8	22.3	27.6	14.7	21.2
11	27.0	16.0	21.5	29.7	14.8	22.3	28.6	14.7	21.7
12	27.0	16.0	21.5	29.0	14.8	21.9	28.6	14.7	21.7
13	28.0	17.0	22.5	29.7	14.8	22.3	28.6	14.7	21.7
14	27.0	16.0	21.5	29.7	14.8	22.3	28.8	14.7	21.8
15	28.0	16.0	22.0	29.0	15.0	22.0	28.8	14.7	21.8
16	28.0	16.0	22.0	28.0	15.0	21.5	28.0	14.0	21.0
17	28.0	15.3	21.7	29.0	14.8	21.9	29.7	14.7	22.2
18	29.0	15.0	22.0	29.7	14.0	21.9	29.7	14.7	22.2
19	29.0	15.0	22.0	29.0	14.8	21.9	29.7	14.7	22.2

20	29.0	15.0	22.0	29.0	15.0	22.0	29.7	14.7	22.2
21	29.0	15.0	22.0	29.7	14.8	22.3	29.0	15.0	22.0
22	29.0	16.0	22.5	29.0	14.0	21.5	29.0	14.7	21.9
23	29.1	15.0	22.1	29.0	14.0	21.5	30.0	14.4	22.2
24	29.0	15.0	22.0	29.0	15.0	22.0	30.3	14.4	22.4
25	28.0	16.0	22.0	28.0	14.0	21.0	30.0	14.4	22.2
26	29.0	15.0	22.0	29.0	15.0	22.0	30.3	14.4	22.4
27	29.1	15.0	22.1	29.7	14.3	22.0	30.0	14.0	22.0
28	28.0	16.0	22.0	29.0	14.3	21.7	30.3	14.4	22.4
29	28.0	15.0	21.5	29.7	15.0	22.4	30.3	14.4	22.4
30	28.0	15.0	21.5	30.0	14.0	22.0	30.3	14.4	22.4
31	29.0	15.0	22.0	30.3	14.3	22.3			

SITE: SOUTH NYANZA AWENDO

	Jul-12			Aug-12			Sep-12		
Date	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
1	27.2	15.0	21.1	27.0	13.2	20.1	28.5	16.0	22.3
2	27.0	17.0	22.0	28.0	14.5	21.3	27.5	14.0	20.8
3	27.5	12.0	19.8	27.5	12.5	20.0	28.9	14.3	21.6
4	27.0	12.4	19.7	272.0	14.7	143.4	28.1	14.0	21.1
5	26.1	13.5	19.8	28.0	15.0	21.5	28.8	13.7	21.3
6	30.0	14.2	22.1	29.0	16.0	22.5	28.2	14.5	21.4
7	29.2	13.0	21.1	28.0	15.0	21.5	27.6	13.0	20.3
8	28.5	12.0	20.3	27.0	14.0	20.5	27.2	14.5	20.9
9	27.0	13.5	20.3	27.5	14.5	21.0	27.4	14.7	21.1
10	27.0	13.0	20.0	27.5	12.5	20.0	28.0	15.0	21.5
11	27.5	13.0	20.3	27.0	13.5	20.3	28.8	13.1	21.0
12	28.0	14.5	21.3	27.2	14.0	20.6	27.1	13.5	20.3
13	28.2	13.0	20.6	27.6	13.5	20.6	27.5	14.2	20.9
14	27.5	12.5	20.0	28.0	12.5	20.3	27.0	13.7	20.4
15	28.0	14.0	21.0	27.0	14.0	20.5	28.5	14.5	21.5
16	27.5	13.5	20.5	27.4	15.2	21.3	29.7	15.3	22.5
17	27.3	14.4	20.9	27.0	14.5	20.8	27.3	13.2	20.3
18	26.5	14.5	20.5	28.0	1.0	14.5	28.5	13.0	20.8
19	26.0	12.0	19.0	27.2	14.0	20.6	29.1	14.0	21.6

20	27.0	15.5	21.3	28.0	13.0	20.5	30.1	13.0	21.6
21	28.5	14.5	21.5	30.0	12.0	21.0	29.8	14.0	21.9
22	28.7	14.3	21.5	29.2	14.5	21.9	30.0	14.5	22.3
23	27.2	13.7	20.5	28.5	14.7	21.6	28.6	14.0	21.3
24	26.8	14.5	20.7	28.2	15.0	21.6	28.1	13.5	20.8
25	26.2	13.3	19.8	28.5	15.7	22.1	27.6	15.0	21.3
26	27.6	13.0	20.3	27.5	14.5	21.0	29.0	14.0	21.5
27	27.3	12.5	19.9	26.6	13.5	20.1	27.2	13.0	20.1
28	27.2	15.0	21.1	28.0	14.2	21.1	27.8	13.0	20.4
29	26.0	13.7	19.9	29.0	14.0	21.5	27.9	15.3	21.6
30	28.5	15.0	21.8	28.0	13.5	20.8	27.5	14.8	21.2
31	27.1	14.0	20.6	27.2	13.0	20.1			

Appendix 3: Experimental Design

REPLICATION 1

BLOCKS

	T_{25}	T_{17}	T_{24}	T_{18}	T_{21}
1	T_{23}	T_{16}	T_{8}	T_{4}	T_{10}
2	T_{19}	T_{20}	T_{13}	T_{9}	T_{15}
3	T_{5}	T_{2}	T_{14}	T_{1}	T_{12}
4	T_{7}	T_{22}	T_{6}	T_{3}	T_{11}
5					

REPLICATION 2

1	T_{1}	T_{6}	T_{11}	T_{16}	T_{21}
2	T_{2}	T_{7}	T_{12}	T_{17}	T_{22}
3	T_{3}	T_{8}	T_{13}	T_{18}	T_{23}
4	T_{4}	T_{9}	T_{14}	T_{19}	T_{24}
5	T_{5}	T_{10}	T_{15}	T_{20}	T_{25}

REPLICATION 3

1	T_{1}	T_{10}	T_{14}	T_{18}	T_{22}
2	T_{2}	T_{6}	T_{15}	T_{19}	T_{23}
3	T_{3}	T_{7}	T_{11}	T_{20}	T_{24}
4	T_{4}	T_{8}	T_{12}	T_{16}	T_{25}
5	T_{5}	T_{9}	T_{13}	T_{17}	T_{21}

Appendix 4: Experimental Model

Source of variation	Df	Sum of squares	Mean squares	Expected mean square. (EMS)
Genotypes (G)	24			$\delta_e^2 + 225\ \delta_G^2$
Locations (L)	2			$\delta_e^2 + 27\ \delta_L^2$
GxL Interaction(GL)	48			$\delta_e^2 + 9\ \delta_{GL}^2$
Replications(R)	2			$\delta_e^2 + 225\ \delta_R^2$
Error (ε_{ijkl}) (E)	148			δ_e^2
Total	**224**			

Appendix 5: LSD for Germination at 45 DAP in South Nyanza Awendo

Genotype	Mean	T Grouping						
KEN 82-601	33.33				A			
KEN 82-121	27.41		B		A			
KEN 04-1320	27.22		B		A			
KEN 82-493	26.11		B		A		C	
KEN 04-1454	25.19		B		D		C	
KEN 04-1603	23.52		B	E	D		C	
KEN 04-100	23.15	F	B	E	D		C	
KEN 04-2765	22.41	F	B	E	D		C	G
KEN 04-710	21.85	F	B	E	D		C	G
KEN 04-2274	21.67	F	B	E	D		C	G
KEN 04-419	20.19	F	B	E	D	H	C	G
KEN 04-1564	19.26	F	I	E	D	H	C	G
D8484 STD	18.7	F	I	E	D	H	C	G
KEN 04-1809	18.52	F	I	E	D	H	C	G
KEN 04-1079	17.59	F	I	E	D	H	J	G
KEN 04-2153	16.67	F	I	E	K	H	J	G
KEN 04-326	15.93	F	I	E	K	H	J	G
KEN 04-2349	15.74	F	I	E	K	H	J	G
KEN 04-762	15.37	F	I		K	H	J	G
KEN 04-2010	15.19		I		K	H	J	G
EAK 73-335	14.82		I		K	H	J	G

STD					
KEN 04-423	12.59	I	K	H	J
KEN 04-2192	11.67	I	K		J
KEN 83-737	9.81		K		J
STD					
KEN 82-472	9.63		K		

Note: Means with the same letter are not significantly different at $p \leq 0.01$ and $p \leq 0.05$

Appendix 6: LSD for Tillers at 7 months in South Nyanza Awendo

Genotype	Mean	T Grouping						
KEN 04-2765	510				A			
KEN 04-100	506		B		A			
KEN 04-1320	500		B		A			
KEN 82-601	498		B		A		C	
KEN 04-419	498		B		A		C	
KEN 04-2010	471		B	D	A		C	
KEN 04-710	469		B	D	A		C	
KEN 82-493	461	E	B	D	A		C	
KEN 04-1809	460	E	B	D	A		C	
KEN 04-1603	450	E	B	D	A		C	F
KEN 83-737 STD	445	E	B	D	A		C	F
KEN 04-326-	442	E	B	D	A		C	F
KEN 04-2349	435	E	B	D	A		C	F
KEN 04-2274	432	E	B	D	A	G	C	F
KEN 04-423	426	E	B	D	A	G	C	F
KEN 04-1454	421	E	B	D	A	G	C	F
D 8484 STD	412	E	B	D	H	G	C	F
KEN 04-1564	400	E		D	H	G	C	F
EAK 73-335 STD	394	E		D	H	G		F
KEN 04-1079	383	E		D	H	G		F
KEN 04-2153	382	E		D	H	G		F

KEN 82-472	370	E	H	G	F
KEN 04-762	361		H	G	F
KEN 82-121	336		H	G	
KEN 04-2192	321		H		

Note: Means with the same letter are not significantly different at p≤0.01 andp≤0.05

Appendix 7: LSD for Germination at 45 DAP in Mumias

Genotype	Mean	T Grouping		
KEN 04-710	50.56		A	
KEN 04-326	48.89	B	A	
KEN 04-2349	48.15	B	A	
KEN 04-2274	47.59	B	A	
KEN 04-1454	44.44	B	A	C
KEN 04-1564	42.41	B	A	C
KEN 04-1603	42.41	B	A	C
KEN 82-121	42.22	B	A	C
KEN 04-2010	42.22	B	A	C
KEN 82-472	39.63	B	A	C
KEN 83-737 STD	37.78	B	A	C
KEN 04-423	37.59	B	A	C
EAK 73-335 STD	36.48	B	A	C
KEN 04-762	35.37	B	A	C
KEN 04-100	34.07	B	A	C
KEN 04-2153	33.70	B	A	C
KEN 82-493	33.15	B	A	C
KEN 04-1079	32.96	B	A	C
KEN 04-1320	32.41	B	A	C
KEN 04-1809	31.11	B	A	C
KEN 04-2765	30.19	B	A	C

D8484 STD	26.11	B	C
KEN 04-419	23.89		C
KEN 04-2192	23.52		C
KEN 82-601	22.96		C

Note: Means with the same letter are not significantly different at $p \leq 0.01$ and $p \leq 0.05$

Appendix 8: LSD for Tillers at 7 months in Mumias

Genotype	Mean	T Grouping			
KEN 04-419	372			A	
KEN 04-710	356	B		A	
KEN 04-2765	355	B		A	
KEN 04-326	349	B		A	C
KEN 04-1603	344	B		A	C
KEN 04-1320	309	B	D	A	C
KEN 04-2192	300	B	D	E	C
KEN 04-1454	294 F	B	D	E	C
KEN 04-1809	291 F	B	D	E	C
KEN 82-493	286 F	G	D	E	C
KEN 04-100	285 F	G	D	E	C
KEN 04-2349	275 F	G	D	E	H
EAK 73-335 STD	273 F	G	D	E	H
KEN 04-2010	265 F	G	D	E	H
KEN 82-472	261 F	G	D	E	H
KEN 04-762	257 F	G	D	E	H
KEN 04-2274	255 F	G	D	E	H
KEN 04-423	252 F	G	D	E	H
KEN 04-1079	241 F	G		E	H
D 8484 STD	232 F	G		E	H

KEN 04-2153	231	F	G			H
KEN 83-737 STD	219		G			H
KEN 04-1564	209					H
KEN 82-601	131				I	
KEN 82-121	118				I	

Note: Means with the same letter are not significantly different at $p \leq 0.01$ and $p \leq 0.05$

Appendix 9: LSD for Germination at 45 DAP in Kibos

Genotype	Mean	T Grouping						
KEN 04-1603	84.07				A			
KEN 04-1079	80		B		A			
KEN 04-326	79.44		B		A		C	
KEN 04-710	76.3		B	D	A		C	
KEN 04-1809	75.56	E	B	D	A		C	
KEN 82-493	73.52	E	B	D	A		C	
KEN 04-423	70	E	B	D	A		C	F
KEN 04-2765	69.82	E	B	D	A		C	F
EAK 73-335 STD	69.63	E	B	D	A		C	F
KEN 04-419	68.89	E	B	D	A		C	F
KEN 04-2274	67.22	E	B	D	A	G	C	F
KEN 83-737 STD	66.85	E	B	D	A	G	C	F
KEN 04-762	65.56	E	B	D	H	G	C	F
KEN 04-2010	64.07	E	B	D	H	G	C	F
KEN 04-2153	63.15	E	B	D	H	G	C	F
KEN 04-1564	62.04	E		D	H	G	C	F
KEN 82-472	59.82	E		D	H	G		F
KEN 04-1454	59.07	E		D	H	G		F
KEN 04-100	58.89	E		D	H	G		F
D8484 STD	58.7	E		D	H	G		F

KEN 04-2349	58.15	E		H	G	F
KEN 04-1320	52.78			H	G	F
KEN 04-2192	50.93		I	H	G	
KEN 82-121	48.33		I	H		
KEN 82-601	33.33		I			

Note: Means with the same letter are not significantly different at $p \leq 0.01$ and $p \leq 0.05$

Appendix 10: LSD for Tillers at 7 months in Kibos

Genotype	Mean	T Grouping			
KEN 04-326	266			A	
KEN 04-1603	241	B		A	
KEN 04-1809	236	B		A	C
KEN 04-2192	228	B		D	C
KEN 04-1564	228	B		D	C
KEN 04-1454	227	B	E	D	C
STD KEN 83-737	216	B	E	D	C
KEN 04-710	215	B	E	D	C
KEN 04-100	214	B	E	D	C
KEN 04-2765	213	B	E	D	C
KEN 82-493	213	B	E	D	C
KEN 04-423	212	B	E	D	C
KEN 82-472	212	B	E	D	C
KEN 04-2274	212	B	E	D	C
KEN 04-1079	212	B	E	D	C
KEN 04-2349	211	B	E	D	C
KEN 04-2010	210		E	D	C
STD EAK 73-335	209		E	D	C
KEN 04-1320	209		E	D	C
KEN 04-2153	204		E	D	
KEN 04-762	203	F	E	D	

KEN 04-419	197	F	E	G
STD D 8484	173	F		G
KEN 82-601	172			G
KEN 82-121	128			H

Note: Means with the same letter are not significantly different at p≤0.01 and p≤0.05

Pictures showing planting of the GEI trial at Mumias Sugar Company

Source: Author, 2012

Picture showing quality assessment using hand refractometer

Source: Author, 2013

Supervisors assessing the trial at SRI Kibos

Source: Author, 2013

Supervisors assessing the trial at South Nyanza Sugar Company

Source: Author, 2013

Harvesting and yield estimation

Source: Author, 2015