# POTENTIAL OF USING MAIZE STALKS FOR FUEL ETHANOL PRODUCTION

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## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university or any other award.

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# DEDICATION

I dedicate the work done in this study to my children, Wanja, Ndirangu and Njeri, my dear husband, Wangai and my loving mum and dad.

## ACKNOWLEDGEMENT

It is through the guidance of God almighty that I was able to complete this research, glory to his holy name. I acknowledge with deep gratitude all those persons and institutions that in whatever little way supported me through my research. Special thanks to my supervisors, Prof. T.F.N. Thoruwa and Prof. E.N.M. Njagi, both of Kenyatta University, who guided me all through from the proposal development, the research work and thesis write up, Dr. Peter N. Kiarie of Nairobi University, Mr. Muchiri, the farm manager of KARI-NARL and Mr. David Karanja of KARI-Katumani who assisted me in growing the maize. I acknowledge the help of Mr. Karanja, Department of Food Technology, JKUAT and Mr. Momanyi, KIRDI, in my laboratory testing and analysis. I thank the KIRDI management for allowing me time off to do my studies, in particular Dr. M.C.Z. Moturi who facilitated my study leave. To my family, whose support and encouragement brought me this far, niwega muno.

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ACFC | Agro-Chemical and Food Company limited |
| CAN | Calcium Ammonia Nitrate |
| DAP | Di-Ammonium Phosphate |
| DLC | Dry Land Composite |
| DMoA | Dutch Ministry of Agriculture |
| ERC | Energy Regulatory Commission |
| ES | Economic Survey |
| GAIN | Global Agriculture Information Network |
| HPLC | High Performance Liquid Chromatography |
| KARI | Kenya Agricultural Research Institute |
| KEP | Kenya Ethanol Plant |
| MoA | Ministry of Agriculture |
| MoE | Ministry of Energy |
| NARL | National Agricultural Research Laboratories |
| NGO | Non-Governmental Organization |
| RBA | Russia Biofuel Assocation |
| SPSS | Statistical Package for Social Sciences |
| S1 | Stage 1 (Silking stage) |
| S2 | Stage 2 (Milk stage) |
| S3 | Stage 3 (Dry stage) |
| SD | Science Daily |
| TPC | Total Product Cost |

| | |
|---|---|
| UNDP | United Nations Development Programme |
| USA | United States of America |
| USANRC | United States of America National Research Council |
| WWI | World Watch Institute |

**ABSTRACT**

In Kenya, a country that has not been successful in getting its own fossil fuel deposits, the main material used for ethanol production has been molasses but its supply compared to demand is becoming limited. There is need for alternative materials to produce ethanol without affecting food supply. This study investigated the potential of juice from maize stalks grown locally and normally a byproduct of maize farming, for production of fuel ethanol. Selected Kenyan maize varieties were grown in two seasons, March and September of year 2008. This was done under typical field conditions and sampled at three growth stages, the silking, the milk stage and dry maize stage. Maize varieties for three agro-ecological zones in Kenya were used, the low dry lands, the medium altitude and the highlands varieties. The juice was extracted by crushing the stalks with a 3-roller mill sugarcane crusher and analyzed for total sugars using a digital refractometer (NR-151, China) and specific sugars using a high performance liquid chromatography (HPLC) with a reverse phase column and refractive index detector (RID). The juice was then fermented using baker's yeast (Saccharomyces cerevisiae) at constant temperature of $27^0$C and a pH range of 4-5, distilled at 78 $^0$C and the yield of alcohol determined. The ethanol obtained was tested in a Chinese wick stove (wheel brand model 62) for fuel properties (specific fuel consumption, fire power, burning rate and thermal efficiency) for domestic cooking application. Its performance was compared to that of kerosene fuel. The highest juice yield obtained was 176.67ml/stalk (18840litres/hectare) for maize variety HB625 at the green maize stage, while the lowest was 8.33ml/stalk (616litres/hectare) for variety Katumani in the dry maize stage. The two varieties also had the highest and lowest ethanol yields at 1445.5litres/hectare and 42litres/hectare respectively. Hybrids had the highest juice and ethanol yields per hectare. The three main sugars identified in the maize stalk juice were sucrose, glucose and fructose. The trend for the sugars was a decrease for fructose and glucose and an increase in sucrose as the maize plant matured. Ethanol obtained burnt with a blue flame compared to the yellow flame of kerosene, with a power output of 1.08kW and a thermal efficiency of 38.2%. However, about 2 times the quantity of fuel and heating time was required for ethanol compared to kerosene to bring to boiling point the same amount of water at the same conditions. The average cost of producing 1litre of ethanol (93%v/v) from the maize stalks was found to be KSh.63.56 (about 1USD). The study has contributed positively to the search for a clean sustainable energy resource and consequently reduction of dependence on the fossil petroleum fuels in Kenya and other countries. Use of maize stalks as feedstock for ethanol production gives a renewable source of energy for the motor industry and for domestic cooking. Maize grows in plenty in Kenya and this can boost energy security for the country and also contribute to economic growth for the country, specifically the rural economy through diversification of the agro-industry.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Energy is a key factor in economic production and growth. In Kenya, the commercial energy sector is dominated by petroleum which accounts for 22% (Wanambwa, 2005), yet all this is imported since Kenya does not have any fossil fuel deposits, and spends huge revenue to import the fuel. The petroleum import bill for the year 2006 was KSh.113 billion (1760 million USD) up from KSh.95 billion (1460 million USD) for the year 2005 (ES, 2007). There was a further 7.1% increase to KSh.121.8 billions in year 2007 (ES, 2008). Based on the concept of sustainable development, Kenya's reliance on petroleum fuel imports as the major commercial fuel is unsustainable; therefore it is necessary to shift to alternative fuels. Since the fuel crisis of the mid 1970's, there has been a growing interest in renewable bio-fuels yet practical gains have been minimal. The cost of energy has remained consistently high and this has resulted in an increase in the cost of production which implicate on the commodity prices and their competitiveness. Cognizant of this fact, Sessional Paper on Energy (MoE, 2004), highlights the government's position on development of reliable, sustainable and affordable energy supply as a national priority. To help achieve this objective the government is keen to promote development of indigenous energy resources and in particular those that are also environmental friendly. Part of the efforts in this direction would be to explore the potential of locally grown plants as sources of alternative fuel (MoE, 2004). Alternative bio fuel sources would serve a two-fold objective; first to save the country foreign exchange and secondly cushion the country from the effects of increased crude oil prices. Bio fuel is generally cleaner in terms of combustion by-products and emissions (Yacobucci, 2006); hence its use would contribute to a cleaner environment. After the 1980's oil crisis, ethanol was produced as a fuel to extend gasoline stocks but now it's mainly used as a gasoline additive for its oxygen and octane content (Coyle, 2007).

The 1970's conditions of high oil prices and low sugar prices motivated the Kenyan government to invest in ethanol production. In 1983, the first ethanol plant was successfully installed as an annex to the Muhoroni sugar factory in Nyanza Province (HABITAT, 1993). The ethanol produced was used as a blend with gasoline with 10% ethanol and 90% fossil gasoline (HABITAT, 1993; MoE, 2004). Ten years later the plant was closed down due to mismanagement and pricing problems. Since then the country has continued to rely largely on petroleum fuel imports for transport operations consuming about two thirds of all the petroleum fuel in the country (MoE, 2004; Wanambwa, 2005). However the government intends to reintroduce power alcohol as a motor fuel as a long term policy to enhance security of energy supply (MoE, 2004). According to a report on status and prospects of biofuels in Eastern and Southern Africa (Karekezi et al., 2008), the daily ethanol production in Kenya was 57,400 litres by Agrochemicals and Food Company Ltd. (ACFC) and Kisumu Ethanol Plant.

There was however a projection to increase the production to 340,000 litres per day by increasing the capacity of the two producers and introduce a third producer, the Mumias Sugar Company.

Going by the global trends the potential for ethanol fuel is apparent. The global production for fuel ethanol constituted about 86% of all bio-fuel production (WWI, 2007). Bioethanol production increased from 17.25 billion liters in the year 2000 to 46 billion liters in the year 2007 (Balat, 2009). Varying raw materials are in use to produce ethanol including cellulosic materials like switch grass, starches like corn and wheat and simple sugars like sugarcane and sweet sorghum (WWI, 2007). India and China are already producing ethanol from sorghum stalks. The varieties of sorghum being used for this purpose are able to give both high yields of grain and stem juice with high sugar levels (UNDP, 1994).

**1.2 Problem statement and Justification**

Kenya does not have any known reserves of fossil fuel and relies entirely on imported fuel whose supply is not certain and whose price keeps going up, resulting to huge spending. As such there is need for an alternative fuel which can substitute the gasoline and bring down the cost of fuel. Some raw materials including sugarcane, corn, wheat and cassava, which have been used for ethanol production, are either food or take up agricultural land for their cultivation without yielding food and this poses a huge challenge to food security. At the present no biofuel is being processed in Kenya to substitute gasoline. The power ethanol production from sugarcane initiated in 1978 at Muhoroni failed due to infrastructural and policy problems.

Maize crop which gives rise to maize stalks is a staple food and is grown in every province in Kenya with about 1.9 million hectares cultivated for maize growing in the country. The maize stalks which are a by-product from maize farming, offers an appropriate feedstock for ethanol production. There is no evidence of work undertaken on ethanol production from maize stalks in Kenya and other African countries. Maize stalks are either fed to animals or left in the farms to rot.

Successful production and use of fuel ethanol to supplement fuel use in the transport sector will result into a reliable, renewable and cleaner fuel. Also, ethanol can be used as a cooking liquid fuel, considering that 80% of the Kenyan population is dependent on solid biomass for fuel for domestic cooking. This will promote the economy and preserve the environment.

### 1.3 Hypothesis

Maize stalks from maize varieties growing in Kenya contain sufficient juice and fermentable sugars for bioethanol production.

## 1.4 Objectives

The main objective of this project was to determine the potential of maize stalks locally grown in Kenya for production of fuel ethanol. The specific objectives were to:

1. Determine maize stalk juice yield for some selected maize varieties growing in Kenya at various growth stages;
2. Establish the sugar content and types present in the maize stalk juice at various growth stages;
3. Determine the ethanol yield from maize stalk juices per given area of cultivation for varieties under study;
4. To demonstrate the suitability of fuel ethanol for domestic cooking application by determining the thermal efficiency, the fire power, the specific fuel consumption and the burning rate of the fuel;
5. To determine the ethanol production cost per litre and compare to the prevailing market price for gasoline and kerosene.

## 1.5 Scope and Limitation of the study

The study investigated sixteen maize varieties normally grown in Kenya and was seeking to compare the juice yield, sugar content and ethanol yield of the juice from the maize stalks irrespective of where or when grown. No optimization was done either on the part of growing the maize or on processing the ethanol. The maize was grown as normally done by the farmers using the recommended agricultural practices and the juice and sugar analysis and the ethanol processing were done using data from literature. No similar previous studies on locally grown maize were identified hence no data was available on local maize stalk juice to compare with results obtained in this study.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

The review of the literature provided an overview of the history of ethanol as a fuel, raw materials which have been used to produce ethanol, technologies used for ethanol production and uses and benefits accrued from using ethanol as a fuel. Past research work carried out in these areas was reviewed.

## 2.2 Fuel ethanol

### 2.2.1 Definition and history

Ethanol is an ethyl alcohol made by either biological fermentation of simple sugars such as glucose, sucrose and fructose using micro-organisms (Yacobucci, 2006), or from petroleum through catalytic hydration of ethylene with sulphuric acid. During fermentation, simple hexose sugars are converted to alcohol and carbon dioxide. In its pure form, ethanol is a colourless liquid with mild characteristic odour, boils at $78^0C$ and freezes at $-112^0C$ (Shapouri and Gallagher, 2002).

As a liquid fuel, ethanol is clean burning and can be blended with gasoline and used in normal gasoline engines or used in its pure form in internal combustion engines specially designed for ethanol use (Wanambwa, 2005; DMoA, 2005).

Bio-ethanol was one of the first fuels used in the automobile. A report by the WWI (2007) indicates that the use of fuel ethanol started as early as in the 19th century. It was used by Germans in the First -World War but after the war, gasoline was readily available and replaced the fuel ethanol (Shapouri and Gallagher, 2002). However the fuel crisis of 1970's caused renewed interest in fuel ethanol and since then there has been continued growth in fuel ethanol production and use due to issues related to energy security, high oil prices and environmental concerns among others (Wanambwa, 2005; Batidzirui, 2007).

### 2.2.2 Raw materials for ethanol

Bioethanol is obtained from the conversion of carbon based feedstock, mainly agricultural feedstocks which are considered renewable because they get energy from the sun. Three types of feedstock have been used for fermentation to give ethanol including sugars such as sugarcane, and beet, starches such as maize, cassava, cereals, potatoes and sweet potatoes and cellulosic materials such as wood, boards and grass (Janick and Whipkey, 2002). In the USA corn is mainly used for production of ethanol. Brazil uses sugarcane, China uses corn, wheat and sugarcane while India uses sugarcane and cassava for ethanol production (WWI, 2007). The European Union mainly uses beet and cereals. India and China have initiated use of sweet sorghum stalks for bioethanol production (UNDP, 1994; Rajvanshi and Nimbkar, 2001). Sweet sorghum can be used as a direct source of sugars for fermentation without requiring conversion as in the case of starches and cellulose (Paul, 1980). Varieties of sorghum developed for ethanol production have juice sugar content of up to 20 $^{0}$Brix and ethanol yield above 9% (UNDP, 1994). The main component of sugar in sweet sorghum is saccharose and it increases as the sorghum matures. The saccharose levels relate to the alcohol levels (UNDP, 1994). Kenya, Malawi and Zimbabwe have used sugarcane to produce fuel ethanol though currently in Africa, till recently only Malawi has been producing the fuel ethanol (Wanambwa, 2005; WWI, 2007)

Recent research at the University of Illinois have shown that tropical maize stores sugars in its stalk which can be fermented for ethanol fuel (SD, 2007). According to this report, the juice from these stalks can produce up to 25% sugars mostly glucose, sucrose and fructose hence it's suitability for fermentation to give bio-ethanol. There are many varieties of maize growing in the tropics and therefore it is necessary to establish which varieties would give the best yields and sugar levels.

Different materials give different yields and some of these yields have been improved through research over years. Within the past 25 years, sugarcane yield has improved by 33% due to improvement of sugar content and extraction efficiency (Rahmani and Hodges, 2008). Sweet sorghum yields up to (1378 litres) per acre. Table 2.1 shows ethanol yields for some materials

**Table 2.1: Yields of common crops associated with ethanol production**

| Crop | Yield (litres/ha) |
|---|---|
| Miscanthus | 14,031 |
| Switch-grass | 10,757 |
| Sweet potatoes | 10,000 |
| Sweet sorghum | 8419 |
| Sugar beet | 6679 |
| Sugar cane | 6192 |
| Cassava | 3835 |
| Wheat | 2591 |

Source: Russian bio-fuels association report, 2008

### 2.2.3 Maize

Maize grain has been used for ethanol production for a long time. In the USA, it is the main raw material for fuel ethanol production (WWI, 2007). However, it is only recently that research into use of the stalks has started (SD, 2007). Tropical Maize stalk juice contains simple sugars such as glucose, fructose and sucrose at varying concentrations (SD, 2007). In Kenya, maize is grown mainly as a staple food in nearly all districts (MoA, 2007). The maize production in Kenya has been on an upward rise with for example an increase of 11.5% from 32.4 million bags recorded between the year 2005 and 2006 (MoA, 2007).

The research at Illinois University proposes that ethanol can be produced from maize stalk juice of the tropical maize plants, due to its high content of simple sugars. The maize stalk requires less processing than the corn grain, corn stover or switch grass currently being studied as a possible source of bio ethanol (SD, 2007).

In Kenya, maize was introduced by the white settlers in the 1900s and is grown as staple food in almost every part of the country with about 90% of the population depending on maize as an income generating commodity (Nyameino *et al.*, 2003; MoA, 2005). Kenya's annual maize production stands at 2.52 million metric tons from an estimated crop area of 1.9 million hectares (MoA, 2005). A study by the Ministry of Agriculture suggests that there is a potential to expand the area under production fivefold (MoA, 2005). In the year 2006, production for 54 districts recorded the least maize production as 21,080 bags in Meru South and the highest production as 3,605,574 bags in Uasin Gishu district (Agatsiva and Situma, 2006).

Different varieties are grown in Kenya depending on the altitude, amount of rainfall and type of soil. Maize varieties include H 614, H625-27 for high altitude high rainfall areas like Uasin Gishu, parts of Rift valley and the tea zones of Central and Eastern provinces, H 511-13 for medium potential areas and dry land composites for marginal low rainfall areas (MoA, 2002). The spacing recommended for the maize plant is 75cm x 25cm for high potential areas, 75cm x 30cm for medium potential areas and 90cm x 30cm for the marginal areas

(MoA, 2002). Table 2.2 gives different maize varieties grown in Kenya and their associated agro-ecological zones and maturity period.

**Table 2.2: Characteristics of some maize varieties growing in Kenya**

| Maize variety | Ecological Zone | Maturity period (months) |
|---|---|---|
| HB513 | Medium potential and medium altitude | 5 |
| HB516 | Medium potential and medium altitude | 5 |
| MU03022 | Medium potential and medium altitude | 4-5 |
| MU03017 | Medium potential and medium altitude | 4-5 |
| PHB30079 | Medium potential and medium altitude | 4-5 |
| DLC | Dry land | 3 |
| KATUMANI | Dry land | 3 |
| DH01 | Dry land | 3 |
| DH02 | Dry land | 3 |
| HB614 | High potential/ high altitude | 6 |
| HB625 | High potential/ high altitude | 6 |
| HB626 | High potential/ high altitude | 6 |
| HB628 | High potential/ high altitude | 6 |

(Compiled from KARI and Kenya Seeds Co. Farmers guides, nd.)

Literature search indicates that the sugar composition of maize stalk juice of locally grown Kenyan maize varieties and their potential for ethanol production capacities have not been characterized.

### 2.2.4 The Sugars

Glucose is a dextrose present in all plant organs and tissues. It is the primary material of plant photosynthesis. As a reducing sugar, glucose can be fermented by saccharomycete. This yeast metabolizes ethanol from glucose under anaerobic conditions (Najafpour and Lim, 2002). In fermentation, Acetic aldehyde and

Carbon dioxide are produced through decarboxylation of pyruvic acid formed from the dehydrogenation of glucose, then acetic aldehyde is dehydrogenated and alcohol produced (UNDP, 1994). Fructose is a carbohydrate and is a simple sugar mainly found in fruits. It is the sweetest of all sugars. It is a hexose with reducing properties. Sucrose is a disaccharide with non-reducing properties. It is found in all photosynthetic plants as the main product of photosynthesis and as the main form of storage and transportation of carbohydrates (UNDP, 1994). In sugar crops, the majority of the 6-carbon sugars occur individually or in bonded pairs. These sugars are already in a form that can be utilized by the yeast and the only processing required for this crop prior fermentation is crushing to extract the sugars (Paul, 1980).

### 2.2.5 Ethanol processing technologies

#### 2.2.5.1 General process

Ethanol can be made synthetically from petroleum or by microbial conversion of biomass materials (Janick and Whipkey, 2002; Shapouri and Gallagher, 2002; Paul, 1980). The primary synthetic route is the catalytic hydrolysis of ethylene from petroleum while the primary microbial biomass conversion is fermentation followed by distillation (Paul, 1980; USANRC, 1983).

Fermentation process:

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2CO_2$ (Paul, 1980) [ 1]

Hydrolysis of ethylene (USANRC, 1983):

$CH_2{=}CH_2 + H_2O \rightarrow C_2H_5OH$ [2]

Bio-ethanol is obtained when the fermentation of biomass is done. The process follows the steps as in Figure 2.1.

**2.2.5.2 Preparation of biomass for fermentation.**

The method of conversion of biomass to a suitable form of fermentation depends on the nature of the material itself. The materials are prepared for fermentation differently depending on whether they are simple sugars, starch or cellulose. The fermentation method uses three steps which are, formation of a solution of fermentable sugars, fermentation of the sugars to ethanol and separation and purification of ethanol formed, by distillation (Shapouri and Gallagher, 2002).

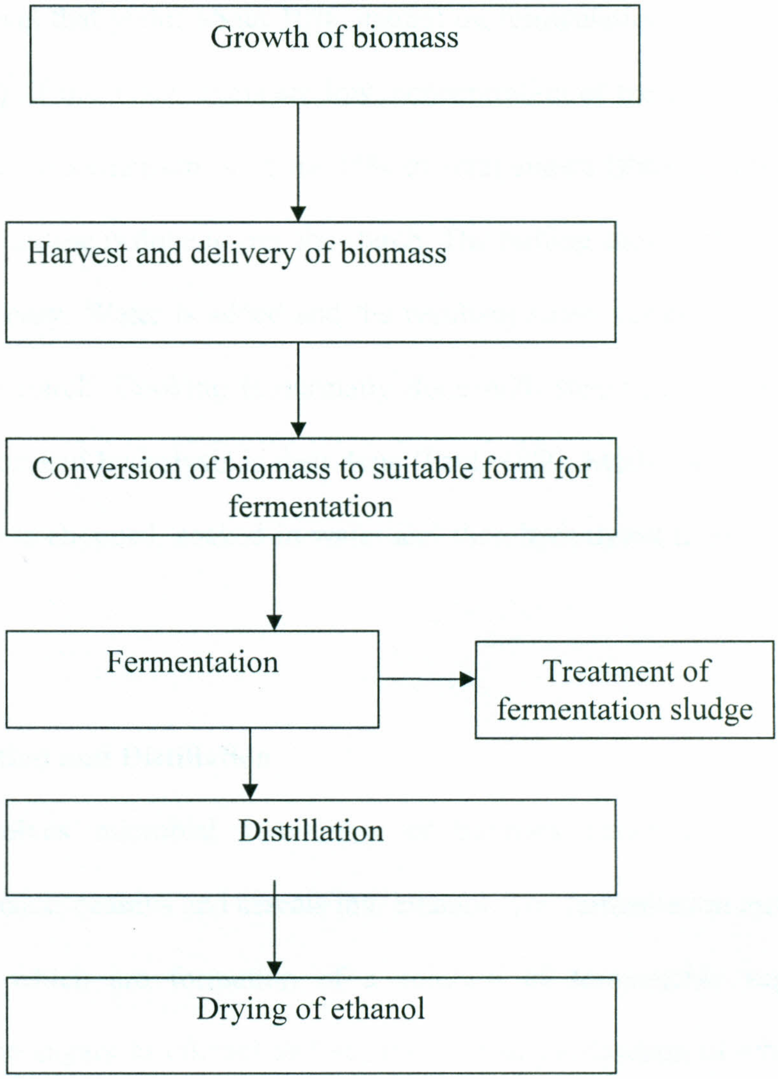


Figure 2.1: Process flow diagram for ethanol production from biomass (USANRC, 1983)

Sugar containing materials (mainly sugar cane, sweet sorghum and beet) are crushed to extract the sugars (UNDP, 1994; Mathewson, 1980). A roller crusher is used for the crushing (UNDP, 1994). ). Extraction of the juice leaves appreciable amounts of sugars in the fibres. An efficiency of between 75% -80% is common for this type of crusher (Mathewson, 1980). The juice obtained is then diluted to achieve a sugar level that yields about 10% alcohol on fermentation (Paul, 1980; Mathewson, 1980). If the sugar levels are low, concentration of the juice is done in evaporators to a concentration of about 15% of total sugars (Paul, 1980). For starchy materials, milling is done to free the starch. The milling should not be fine to make handling easy. Water is added and the resultant slurry cooked to soften and gelatinize the starch. Cooking is normally done with steam in commercial settings. Enzyme or acid hydrolysis is then done (Paul, 1980; Mathewson, 1980). Cellulose material is chopped, soaked in water and then hydrolysed (Paul, 1980; Mathewson,1980).

**2.2.5.3 Fermentation and Distillation**

Fermentation involves microbial conversion of biomass materials such as sugarcane, beet, maize, cassava and cereals into ethanol. The fermentation method uses three steps which are formation of a solution of fermentable sugars, fermentation of the sugars to ethanol and separation and purification of ethanol formed by distillation. The fermentation can either be batch or continuous (Shapouri and Gallagher, 2002)

The most frequently used micro-organism for fermentation is yeast called *Saccharomyces cerevisiae* also known as baker's yeast (Paul, 1980; Janick and Whipkey, 2002). This is because of its fast rate of growth, high tolerance for alcohol and high capacity for producing high yields of alcohol. This yeast operates well within a pH range between 3.0 and 5.0 and a temperature range between 27 $^{0}$C and 35 $^{0}$C (Paul, 1980; Mathewson, 1980). One molecule of hexose sugar yields two molecules of alcohol and two molecules of carbon dioxide as illustrated by *eq. 1* (Paul, 1980)

Fermentation is usually run to give a 10% - 15% ethanol concentration. After fermentation, the product is distilled to give concentrated ethanol. The ethanol, which is produced from the fermentation process, still contains a significant quantity of water, which must be removed. This is achieved by using the fractional distillation process. The distillation process works by boiling the water and ethanol mixture. Since ethanol has a lower boiling point (78.3 $^{0}$C) compared to that of water (100 $^{0}$C), the ethanol turns into the vapour state before the water and can be condensed and separated. To give fuel ethanol, the distillate is dehydrated and denatured by adding a little gasoline (Yacobucci, 2006). The dehydration of ethanol is achieved either by absorption method, drying with lime or azeotropic distillation (Mathewson, 1980).

### 2.2.6 Ethanol uses and benefits

Ethanol is used in the pharmaceutical and cosmetic industries as a solvent and drug. It is also used as a preservative and disinfectant domestically. In the transport sector it is used for processing biodiesel and as a fuel additive to gasoline. Anhydrous ethanol is blended with gasoline and used in petrol engines.

It can also be used in internal combustion engines on its own. When added to gasoline, ethanol acts as an oxygenate, and is being used to replace the methyl t-butyl ether (MTBE), a chemical which causes water and soil contamination (RBA, 2008). This report indicates that a 10% mixture of ethanol with gasoline reduces the chances of knock by raising the octane rating, hence today unlike in the early 1980's when ethanol was produced as a fuel to extend gasoline stocks, it is mainly used as a gasoline additive for its Oxygen and Octane content. Since the complete phase out of lead in commercial vehicles in the United States of America in 1996, ethanol has replaced lead in gasoline to prevent knocking (Morris, 2008). Use of ethanol in an engine improves the combustion efficiency of gasoline because of the Oxygen hence gives better performance. This also reduces emissions of carbon monoxide and unburned hydro-carbons. It generally reduces emissions and is biodegradable.

Most African countries, Kenya included, are net importers of oil. The use of bio-ethanol as a fuel offers a stable, secure and environmental friendly energy supply, as an extender for gasoline supplies. This also reduces cost of oil importation. Growing of the energy crop to process ethanol revitalizes the rural economies by diversifying agricultural industries and creation of jobs (Batidzurui, 2007). There is also increased access to modern energy services.

## 2.3 Fuel ethanol status

### 2.3.1 Global situation

The 1970s' fuel crisis occasioned the need for search for alternative fuels and the continued rise in fossil fuel prices has increased the interest in alternative fuels. There has been a lot of research into bio-fuels as alternative fuel. The global fuel ethanol production doubled between the year 2001 and 2006 and by the year 2007, ethanol accounted for 86% of total bio-fuel production (WWI, 2007). Some of the identified key drivers to this growth are energy security, high oil prices, rural development opportunities, diversification of agricultural industries and environmental commitment (Batidzurui, 2007). Growing of energy crops provides an alternative market for farmers and the processing of the bio-fuels creates new industries providing an extra revenue earner for the rural economies.

USA and Brazil dominate the world's ethanol production which totalled 38.2 billion litres in 2006. The remainder is made in the European Union where Spain, Sweden, France and Germany are the main producers. China and India are also producing ethanol mainly from sugarcane, wheat and cassava (WWI, 2007).

Ethanol production in Africa is concentrated on the southern tip of the continent, with the Republic of South Africa accounting for approximately 70 per cent of the total (Karekezi *et al.*, 2008; Berg, 2001). South Africa started a blending programme in 2007 (Batidzurui, 2007). Zimbambwe had a blending programme between 1980 and 1992, Kenya also blended between 1983 and 1993 but both programmes collapsed. Malawi has blended since 1982 to date. Other countries which have recently started a blending programme include Ethiopia with an E5 (a blend of 5%ethanol and 95% gasoline) mandate in Addis as from 2007, Sudan and Nigeria which is partnering with Brazil and China to create a bio-city (Karekezi *et al.*, 2008; Batidzurui, 2007; Karekezi and Kimani, 2007).

**2.3.2 Kenyan situation**

The Kenyan government initiated a program to distil ethanol from sugarcane in 1978 mixing it in a 10% blend with gasoline but this programme failed due to drought, poor infrastructure and inconsistent policies (Wanambwa, 2005; WWI, 2007). This was being done by the Agro Chemical & Food Corporation (ACFC). The ACFC still runs to date but produces ethanol mainly for domestic and industrial uses (Batidzurui, 2007). Kisumu Ethanol Plant (KEP) was established in 2001 and its commissioning completed in 2004. It also produces ethanol for domestic and industrial use. The main markets for the ethanol produced are the local buyers, Uganda, Rwanda and Central Africa (Karekezi *et al*, 2008). However, the government is keen to re-introduce ethanol in the transport sector (MoE, 2004). By the year 2008, only the two ethanol plants were in production with a production capacity of 27,400 litres per day for ACFC and 30,000 litres per day for KEP. The current installed capacities are 60,000 litres per day and 65,000 litres per day respectively. The Mumias sugar company has a projection of daily production of 50,000 litres (Karekezi *et al*, 2008).

Notable is the fact that biofuels activities in Kenya have been led by Non-Governmental Organizations (NGOs) but the government has taken it up through the Ministry of Energy (Muok *et al.*, 2008). The Sessional paper of year 2004 and the Energy Act enacted in year 2006 brings out the government's commitment to encourage and facilitate wider adoption of renewable energy technologies (MoE, 2006; MoE, 2004). The government constituted a National biofuels Committee which has seen the development of a biodiesel and bioethanol fuels strategies (Muok *et al.*, 2008). The Energy Regulatory Commission (ERC) established in the year 2006 has been mandated to regulate the energy sector in order to ensure a coordinated and comprehensive integration of all energy resources.

**2.4 Ethanol production cost**

The ethanol production costing is done in order to determine the production cost and estimate the selling price for the ethanol fuel (Paul, 1980). Bioethanol consumer prices are determined by the producers costs which in turn are determined by production and logistic chains including tax and sales margin. Production costs for bioethanol include raw material costs, plant operational costs and capital costs (Kane and Reilly, 1989, Chandel *et al.*, 2007). In Kenya, one of the ethanol producers, the Agro-Chemicals and Food Company (ACFC) limited produces ethanol from molasses. Its cost of production consists of the variable costs, fixed costs and depreciation as outlined in Table 2.3 for the years 2006 to 2009.

The cost of the feedstock is an important parameter for low cost ethanol production and the choice of the feedstock depends on the availability and ongoing uses (Chandel *et al.*, 2007). The price floor for bioethanol is determined by the higher value between the production costs and the opportunity costs of alternative agro- industrial application of the feedstock but the price ceiling is determined by the market conditions (Chandel *et al.*, 2007).

The cost of ethanol production per litre varies depending on among other things the efficiency of the process and the type of feedstock used. According to a report by Global Agriculture Information Network (GAIN), production of ethanol from wheat costs about 0.59€/litre (Ksh.66.08/litre) while production using sugar-beet costs 0.6€/litre (KSh.67.2/litre) (GAIN, 2006). In his study, Goldemberg (2009) gives the cost of ethanol production from sugar-beet as 0.52€/litre (Ksh 58.2/litre), the cost while using corn as 0.25€/litre (KSh.28/litre) and while using sugarcane as 0.15€/litre.

**Table 2.3: Cost (KSh.) for production per unit liters of neutral spirit**

| | Jun-09 | Dec-08 | Mar-07 | Dec-06 |
|---|---|---|---|---|
| **Variable costs (KSh.)** | | | | |
| Molasses | 13.04 | 11.87 | 8.79 | 8.98 |
| Chemicals | 1.88 | 2.06 | 1.06 | 1.12 |
| Electricity | 1.87 | 2.07 | 1.22 | 1.38 |
| Transport | 0 | 0 | 0 | 0 |
| Storage/handling | 0 | 0 | 0 | 0 |
| Steam | 5.92 | 7.74 | 4.48 | 4.39 |
| | **22.71** | **23.74** | **15.55** | **15.87** |
| **Fixed costs(KSh.)** | | | | |
| Salaries, wages &benefits | 9.09 | 9.28 | 7.82 | 7.09 |
| Administrative expenses | 6.16 | 5.72 | 5.04 | 6.93 |
| Interest & finance charges | -2.4 | -3.85 | 0.03 | 0.04 |
| Repairs and maintenance | 2.21 | 1.96 | 2.1 | 1.93 |
| | **15.06** | **13.11** | **14.99** | **15.99** |
| **Depreciation (KSh.)** | 3 | 4.44 | 4.83 | 3.25 |
| | | | | |
| | **40.77** | **41.29** | **35.37** | **35.11** |
| | | | | |
| **GoK converted loan interests(KSh.)** | 11.7 | 17.32 | 13.3 | 17.93 |
| | | | | |
| **Total cost (KSh.)** | **52.47** | **58.61** | **48.67** | **53.04** |
| Realization **(KSh.)** | 63 | 63 | 55 | 55 |

*Source: Management accounts of ACFC, 2009*

According to the study, the cost of ethanol production from sugar cane has gradually come down from the year 1975 to present due to increased economies of scale, improved processing efficiencies and agricultural gains which have seen introduction of high productivity sugarcane varieties. This has resulted to an improved ethanol yield from 2000 l/ha in 1975 to about 7000 l/ha at the time of study.

### 2.5 Summary of major findings

The review of literature showed that ethanol is being produced in Kenya using molasses as the feedstock, and mainly for other uses as mentioned in section 2.2.6 and not as substitute for gasoline. However the molasses is not sufficient and the producers are seeking to establish alternative and renewable feedstock to sustain their production. Up to date, the ethanol produced in the country is exported and used locally for domestic and industrial purposes. But the government has a plan to reintroduce ethanol as a transport fuel hence a need for a sustainable feedstock supply was identified.

The literature reviewed identified tropical maize stalks as a possible feedstock but there was no evidence of a study done earlier in the tropics to support this. The maize stalk was identified as containing simple sugars which can be fermented to give ethanol. The method of production of ethanol identified by the literature reviewed was through fermentation at constant temperature using baker's yeast followed by distillation of the marsh obtained to give concentrated ethanol.

The cost of ethanol production varies from KSh. 28 to KSh.67 depending on the feedstock. Some of the factors considered in computing production cost include the variable costs, fixed costs and the feedstock cost.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Introduction

Maize stalks of different varieties of maize commonly grown locally in Kenya were used as the samples for investigation. This was done at various stages of growth. The maize was grown under normal field conditions as done practically by most farmers. No irrigation was done and the normal planting seasons were used to grow the maize.

## 3.2 Experimental design

Sixteen maize stalk varieties were grown at Kenya Agricultural Research Institute (KARI) stations in Nairobi and Katumani-Machakos and at the Crop Science Department of Nairobi University, Kabete campus. Two stations of KARI were used for the maize stalk production, one was at the KARI National Agricultural Research Laboratory (NARL) fields, Nairobi ($1^0$17'S $36^0$ 49' E), and the other at Katumani station, Machakos ($1^0$ 35'S $37^0$14'E). The plot provided by the University of Nairobi was at Kabete campus farm ($1^0$ 14'S $36^0$ 43'E).This was in the month of March to August, 2008 and September 2008 to January 2009 (Rainfall pattern for this period is attached in Appendix 10). Each maize variety was planted in a plot of 10 rows of 10 plants (10x10) and randomly sampled for analysis (Abdalla, 2007). The stalks were sampled at three growing stages, the silking stage (when about 50% of the plants had removed the silk), the milk stage

(3 weeks after the silk stage) and the dry maize stage, (about 5weeks after the milk stage) when the maize was assumed to have reached the physiological maturity. The growth stages were identified based on the growth stages for maize growing in the low tropics with a temperature range between $22^0$C -$33^0$C as described by the International Maize and Wheat Improvement Centre, CIMMYT, (www.maizedoctor.cimmyt.org). Upon sampling, the forage from the stalks was removed by hand and the average height and weight of the stalks was recorded. The juice from the stalks was squeezed out using a three roller mill cane crusher and the juice yield determined by measuring the volume. The juices were analysed for specific sugars using high performance liquid chromatography (HPLC) and digital refractometer (NR-151, China) for total sugars then fermented and distilled to determine the ethanol yield. Each test was replicated 3 times.

### 3.3 Maize stalk production

Maize stalk production was done at plots provided by the Kenya Agricultural Research Institute (KARI) and the Crop Science Department of Nairobi University, Kabete campus. Two stations of KARI were used for the maize stalk production, one was at the KARI National Agricultural Research Laboratory (NARL) fields, Nairobi ($1^0$17'S $36^0$ 49' E), and the other at Katumani station, Machakos ($1^0$ 35'S $37^0$14'E). The plot provided by the University of Nairobi was at Kabete campus farm ($1^0$ 14'S $36^0$ 43'E) Different varieties were grown in these plots. The Katumani site falls within the upper midland transitional agro-ecological zone with an average rainfall of 673mm. Its soil is classified as a chromic luvisol, consisting of friable clay, well drained with high water storage capacity and a non-humic top soil (KARI, 1994). The NARL and Kabete sites fall within the upper midland semi humid agro-ecological zone with an average annual rainfall of 981 mm. The soil for the two sites is humic nitisol, a deep clayey and well-drained soil with an acid humic top soil (KARI, 1994).

### 3.3.1 Land preparation

The land was prepared in advance before the onset of rains by ploughing and levelling as recommended (MoA, 2002). Furrows for planting were dug in rows 75cm and 90cm apart for high potential and low potential varieties, respectively, as recommended for planting of maize (MoA, 2002).

### 3.3.2 Maize seed selection

The maize seeds were selected based on what is commonly grown by farmers locally and the suitability to different agro-ecological zones (MoA, 2002). Hybrid seeds and composites for dry areas were selected. HB513, HB516, HB520, HB614, HB624-28 seed varieties were selected from the seeds developed for highlands and medium zones by Kenya Seed Company (MoA, 2002). Varieties DH01 and DH02 were selected as composites developed by the same company for dry areas. The MU03022 and MU03017 varieties were selected from seeds developed by KARI for medium potential zones. DLC and Katumani were selected as dry land composite varieties developed by KARI. The varieties PHB30G19 and PHB30079 were selected from varieties developed by Pioneer Seeds Company and being grown locally. The seeds were bought from the Kenya Seeds Company store in Nairobi in 2kg packages.

### 3.3.3 Maize planting

The maize was planted in two different seasons, the first season planting was on 10$^{th}$ March 2008 and the second season planting was on 12$^{th}$ September 2008. The medium and high potential zones varieties were planted at KARI – National Agricultural Research laboratories (NARL) and Nairobi University, Kabete farm while the dry land composites were planted at KARI, Katumani. The varieties HB513, HB520, HB614, HB624, HB625, HB626 and HB628 were planted at KARI (NARL). The varieties PHB30G19, PHB30079, HB516, MU03022 and MU03017 were planted at Nairobi University, Kabete Campus farm. The Katumani, DH01 and DH02 composites were planted at KARI Katumani. The varieties planted during the first season were DLC, HB513, HB614, HB516, PHB30G19, PHB30079, MU03022 and MU03017. The rest of the varieties were planted during the second season. The spacing used was 75cm x 25cm for maize varieties growing in high potential and medium potential areas and 90cm x 30cm for maize varieties growing in dry areas. A planting of two plants per hole was used (MoA, 2002). Di-Ammonium Phosphate (DAP) fertilizer was applied before planting at the rate of teaspoon per plant, mixed well with the soil and then the seeds were planted (MoA, 2002).

### 3.3.4 Weeding and top-dressing

Weeding was done twice at all the plots as recommended for a healthy maize crop (MoA, 2002). This was at 6 weeks after planting and 4 weeks after the first weeding. It was done manually using a long knife (panga). Top dressing was done using Calcium ammonia-Nitrate (CAN) at 6 weeks after planting for the dry land varieties and after 4 weeks for the other varieties as recommended by Ministry of Agriculture, (MoA, 2002).

### 3.3.5 Maize stalk harvesting

Maize stalks were harvested at 3 stages as indicated in the experimental design. This was done by cutting the stalks at the base next to the soil using a long knife (panga) and removing the forage.

## 3.4 Determination of the juice yield

The maize stalk juice yield was determined at the three growth stages used for sampling.

### 3.4.1 Maize stalk preparation and measurement procedure

The maize stalk was cut from the base just above the soil level using a big knife (panga) and the leaves removed from the stalk manually. Three samples each consisting of four stalks was taken per each sampling stage per maize variety. Therefore for every sampling stage, 12 plants (stalks) were sampled for every variety. Leaves were removed from the stalks and the average height and weight of the stalks was measured using a tape-measure and a weighing balance (CTG-6H+) respectively (UNDP, 1994). The height was taken from the base of the stalk to the point where the tussle begins to form. Height was measured for individual stalks but weight was taken for a sample consisting of 4 stalks, then the weight per stalk taken as the average.

### 3.4.2 Juice extraction

The juice was squeezed out of the stalks using a three roller squeezer (sugarcane crusher), locally made in Kenya, by passing each sample four times manually through the crusher (UNDP, 1994). The three samples taken for each stage were squeezed separately and the juice from each sample collected using a bucket at the receiving end of the crusher. The volume of juice for each sample was measured using a measuring cylinder, and this was divided by the number of stalks crushed to get the juice yield per stalk in millilitres (ml).

Figure 3.1: The 3-roller mill crushing equipment (locally made in Kenya)

### 3.4.3 Calculation of maize stalks population

To calculate the number of maize stalks (plant population) per given area, a spacing of 75cm x 25cm for maize varieties growing in high potential areas and 90cm x 30cm for maize varieties growing in dry areas was used. A planting of two seeds per hole was used (MoA, 2002).

NB: Assumption; a square piece of land was used measuring 1hectare.

1 Hectare = 10,000 $m^2$

Dimensions of the square piece of land = $\sqrt{10000m^2} = 100$ m

For high potential area varieties, $N = 2\,[(100 \div 0.75) \times (100 \div 0.25)]$ [3]

For low potential area varieties, $N = 2\,[(100 \div 0.9) \times (100 \div 0.3)]$ [4]

where N = number of stalks per given area of cultivation (per hectare)

### 3.4.4 Calculation of juice yield per unit area

The calculation of the juice yield was based on a plant population per cultivation area (hectare) and specific plant spacing for a given variety. The calculations were carried out as follows:

The juice yield per stalk ($j_s$) = [average volume of juice per sample ( $J_s$)] ÷ [number of stalks crushed per sample of that stage (n)]

$$js = Js / n \qquad [5]$$

Yield of juice (litres) per area of cultivation (J) = [volume per stalk] × [the number of stalks in the given area]

$$J = js\, N \qquad [6]$$

where;

$j_s$ = juice yield per stalk (ml)

$J_s$ = average sample juice yield (a sample is 4 stalks) (ml)

J = yield of juice per area of cultivation (per hectare) (L)

n = number of stalks per sample

N = number of stalks per given area of cultivation (per hectare)

## 3.5 Determination of the sugar content and types of sugars in the juice

### 3.5.1 System description

The sugar content was measured using a portable digital refractometer, Fig. 3.2, (NR-151,China) , with an automatic temperature compensation (UNDP, 1994, Bartolome *et al.*, 1996). The refractometer operates on the principle of refraction of light. As light passes from air into a liquid, it slows down and changes direction of travel (refraction). The extent of the angle of refraction depends on the concentration of the solids dissolved in the liquid. Different scales are used to measure the refraction, giving the concentration. For sugars, the Brix scale (grams of sugar per 100 grams of water) is used (Hanson, 2006).

The measurements were done when the juice was freshly extracted. About 3ml of the sample were placed in the measuring pot and the refractometer set to give the Brix reading.

The total sugar content and types of sugars were determined using high performance liquid chromatography (HPLC) (Shamsudin *et al.*, 2009, Bartolome *et al.*, 1996, Walter, 1992, Osborn and Voogt, 1978). High Performance Liquid Chromatography (HPLC) is a chemistry based tool for quantifying and analyzing mixtures of chemical compounds. It is a separation technique in which a mobile phase carrying a mixture is caused to move in contact with a selectively absorbent stationary phase.


Figure 3.2: The digital refractometer used

Different components of the sample are carried forward at different rates by the moving liquid phase, due to their differing interactions with the stationary and mobile phases, thereby achieving separation.

All the components of the HPLC machine were manufactured by Shimadzu, Japan. The stationery phase used was reverse phase of $NH_2P$ (5µm) in a 250 x 4.6 mm column. The mobile phase was acetonitrile and water in the ratio 80:20 respectively which was prepared by measuring 800ml acetonitrile and mixing with 200ml of water to make a litre (Shamsudin *et al.*, 2009, Osborn and Voogt, 1978). A Refractive Index detector (RID-6A) was used (Shamsudin *et al.*, 2009, Osborn and Voogt, 1978). The system data integrator was a C-R7A+ series. The mobile phase was degassed for 30 minutes using an ultrasonic water bath (SIBATA- SU-6$^{th}$) and a water aspirator vacuum pump (SIBATA WJ-20).

### 3.5.2 Preparation of test samples (extracted maize stalk juice)

The research samples were prepared by first filtering 100 ml sample with a Whatman 25μm filter paper and then a 0.45 μm micro-filter. The filtered samples were then mixed with acetonitrile (1:1), degassed and injected into the HPLC system, 2 runs per sample using a 30 μL needle. A flow-rate of 0.8ml/min, pressure range of 85 – 100 kgf/cm$^2$, temperature of 35 $^0$C and an injection volume was 30μL per injection were used (Osborn and Voogt, 1978). After the injection of the sample into the machine, the system was allowed to run until the elution was complete and the complete spectra displayed by the system data integrator.

### 3.5.3 Preparation of standard sugar solution samples

Working standards were prepared using standard sucrose, fructose and glucose sugars (Osborn and Voogt, 1978). About 2.5 gm of each sugar was weighed and mixed in a beaker. The sugars were dissolved in 25 ml of distilled water and then topped to 50ml to give a stock solution of concentration of 50 mg/ml. About 25 ml of the stock were then drawn into a 50 ml flask and topped up with acetonitrile. From this, samples of 1mg/ml - 5 mg/ml were prepared and were ran in the HPLC to generate the standard chromatograms. The same procedure was used to prepare pure standard sugar solutions but each 2.5 gm of each sugar was prepared in separate beakers. The operating conditions for the HPLC system used to run the standard sugars were the same as those used to run the research samples i.e. a flow-rate of 0.8 ml/min, pressure range of 85 – 100 kgf/cm$^2$, temperature of 35 $^0$C and an injection volume of 30 μL per injection (Osborn and Voogt, 1978)

**3.5.4 Identification of sugars in maize stalk juice**

Elution time (time taken for a given peak to appear) was used to identify the sugars in the maize stalk juice. The solutions of pure standard sugars were injected into the HPLC system, each sugar at a time and the time taken for the peak to appear for each sugar was recorded (Osborn and Voogt, 1978). The peak time for each sugar was matched to the series of peaks obtained after injection of the mixture standard sugar solution for the three sugars (sucrose, fructose and glucose) and the peaks corresponding to each sugar were identified. The sequence of elution for the three sugars was also identified. Once the elution time and sequence for the three sugars were identified and recorded, the test samples were injected and the elution time and sequence matched to the standards to identify the sugars present in the samples (Osborn and Voogt, 1978).

### 3.5.5 Quantification of sugars in maize stalk juice

The areas of the standard sugars' chromatograms as obtained in 3.5.3 were plotted against the corresponding concentrations to give the standard curves and equations for each sugar. The equation obtained was in the form of:

$(y = mx + c)$. [7]

where; y = area

m, c are constants

x = concentration

The graphs plotted for the standards gave the values of the constants, which were then used to calculate the concentrations of the sugars in the research samples. For the research samples the only unknown in equation 7 was the concentration (x). The concentration for each sugar was calculated using the area of its peak (y) obtained from the plot from the data integrator, and the constants (m, c) from the standard equation for the given sugar. The total sugars were obtained by summing the specific sugars (sucrose, glucose and fructose), (Walter, 1992, Bartolome *et al.*, 1996).

## 3.6 Determination of ethanol yield

### 3.6.1 Fermentation

The stalk juices were fermented using baker's yeast (*Saccharomyces cerevisiae*) purchased from a local supermarket in the form of active dry yeast, at the rate of

4% of the total volume (Paul, 1980, Janick and Whipkey, 2002). Small batches of 100ml to 200ml were loaded into 1liter plastic bottles and pasteurised in a water bath at 80 $^0$C for 30 minutes after which they were cooled to temperatures below 35 $^0$C and the sugar contents determined using a digital Brix meter (NR-151, China). Active dry yeast at the rate of 4% of the total volume of juice was then added to each sample and the samples kept in an incubator ( INB 400, max. temp. 70 $^0$C, 230V) for fermentation at 27 $^0$C (Paul, 1980).

The pH was maintained at 5 and was adjusted using Sulphuric acid (Paul, 1980). Its measurement was done using a pH meter. Sugar levels were monitored during the fermentation period by taking readings of sugar content after every 12 hours using the Brix meter (NR-151, China), until there was no more drop of sugar reading (Paul, 1980).

**3.6.2 Distillation**

After the sugar levels were constant, the ferment was distilled using the standard laboratory scale distillation set up as shown in Fig. 3.3. A 100 ml of the ferment marsh was measured and put in a flask, 10 ml of distilled water was added and the mixture distilled to collect a 100 ml of distillate.

The distillate was collected and its specific gravity determined at 20 $^0$C using a density bottle. Weights of the distillates and distilled water also at 20 $^0$C were used to compute the densities and hence the specific gravity (sg) (Pearson, 1970). The density bottle (50ml) was filled with distilled water and ethanol alternately and weighed.

$$sg = \rho\ sample \div \rho\ water \quad [8]$$

But density = [mass] ÷ [volume]; and volume is constant,

Hence;

$$sg = m\ sample \div m\ water \quad [9]$$

where;

sg = specific gravity

ρ sample = density of sample

ρ water = density of water

m sample = mass of sample

m water = mass of water

The percent alcohol (%v/v) corresponding to the specific gravity obtained was read from a table giving the relationship between specific gravity of alcohol and the proportions of alcohol (Pearson, 1970). The experiments were done in triplicate.

Figure 3.3: Ethanol distillation set-up

The percent yield of ethanol by volume obtained was used to estimate the percent yield of ethanol per given area of cultivation.

$$E = eJ\,(\frac{L}{Ha}.) \qquad [10]$$

where;

E = ethanol yield per hectare (Litres/hectare)

e = ethanol yield in %v/v

J = juice yield per hectare

Assumption: the density of the maize stalk juice is the same as that of water.

To concentrate the ethanol, multiple batch distillation runs were done (Akpan *et al.*, 2005) using a fractionating column shown in Figure. 3.4

Figure.3.4: Fractional distillation of ethanol set-up

### 3.7 Water Boiling Test for ethanol as cooking fuel

The ethanol obtained from the distillation in Fig 3.5 above had a concentration of 93% and was tested for its applicability for domestic cooking by burning it in an ordinary cooking stove and performing tests simulating the cooking process. This was done by performing the standard water boiling test (Bailis *et al.*, 2007).

Water boiling test was carried out as described in the Water Boiling Test (WBT) version 3.0, 2007 prepared by Bailis *et al.*, (2007). This test was performed for the ethanol (93% alcohol as obtained from the distillation process) and for kerosene fuel. The aim of the test was to compare the performance of ethanol as cooking fuel in a stove to that of standard kerosene fuel. Kerosene is the most widely used fuel for cooking using stoves in Kenya with about 94% of the population using kerosene for cooking and lighting (Hannah, 2003)

The test was performed in a closed well ventilated room using a Chinese 8-wick stove (wheel brand model 62). At the beginning of the test, the ambient temperature was measured using a mercury thermometer, the weight of the dry pot and dry empty stove were measured using a balance (CTG- 6H+) and weight recorded. The stove was half filled with kerosene and weighed.

Local boiling point was the reference for the test and it was determined at the start of the test by heating 1kg of water till it boiled. Upon boiling temperature readings were taken for 5 minutes and recorded to give the average as the local boiling point.

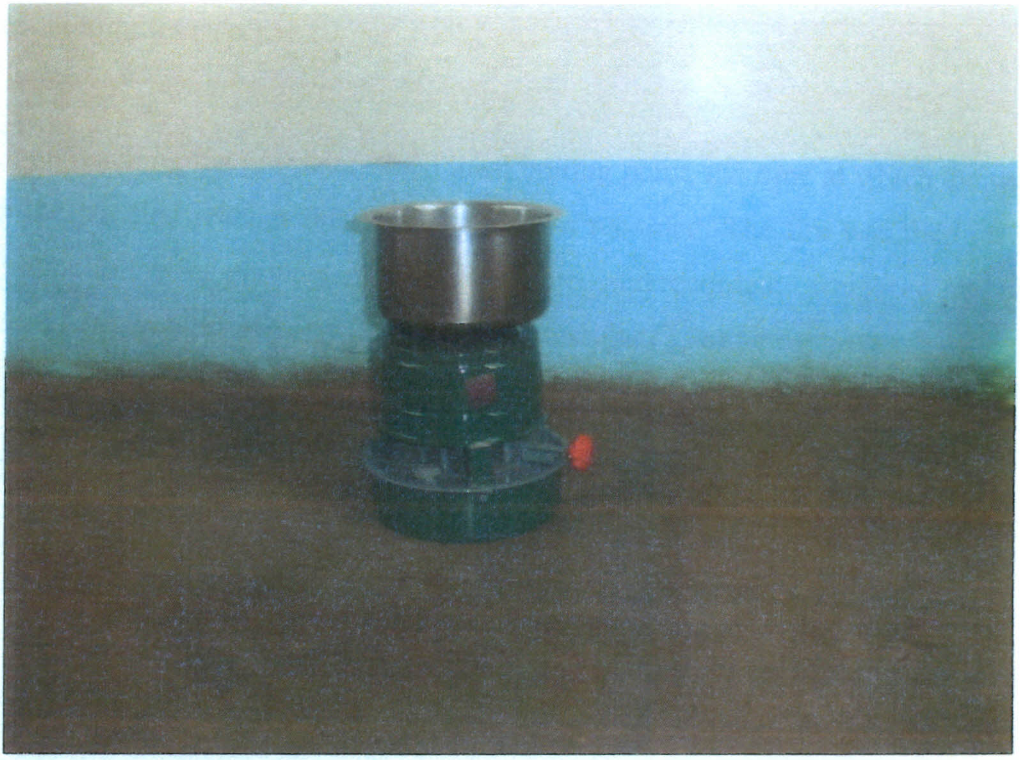

Figure.3.5: Stove and pot used for the Water Boiling Test

The test was first done with kerosene as the fuel, completed, and then replicated with ethanol. For the ethanol test, the stove was cleaned and left to dry and then fixed with new but similar wicks. For each fuel, three runs of the test were done. Between the runs, the stove would be allowed to cool to room temperature so as to achieve a cold start. During each run, 1kg of water was put into the pot and brought to boil.

The following parameters were measured and recorded during the tests: ambient air temperature ($T$), weight of fuel in grams ( $fci$), weight of pot with water before test in grams ($pci$), water temperature before test ($Tci$) and time at start of test in minutes ( $tci$).

Upon reaching the pre-determined local boiling point, the time at which the water in the pot first reaches this temperature was recorded. The fire was then put off and the following parameters were determined and recorded: weight of fuel after test ($fcf$), weight of pot with water after test ($pcf$), water temperature after test ($Tcf$) and time at the end of the test ($tcf$ ).

Using the averages of the data obtained the following variables were calculated as per the illustrations below;

$$Fuel\ consumed\ (fcm)$$

$$fcm = fcf - fci \qquad [11]$$

$$Water\ vaporized(wcv)$$

$$Wcv = pci - pcf \qquad [12]$$

$$Water\ remaining\ at\ the\ end\ of\ the\ test\ (wcr)$$

$$wcr = pcf - p \qquad [13]$$

$$where\ p\ is\ the\ weight\ of\ empty\ pot$$

$$Duration\ of\ phase\ in\ minutes$$

$$(\Delta tc) = tcf - tci \qquad [14]$$

### 3.7.1 Thermal efficiency

$$Thermal\ efficiency\ (hc), the\ ratio\ of\ work\ done\ per\ energy\ consumed$$

$$hc = \frac{4.186\ x\ (pci - p) x\ (Tcf - Tci) + (2260\ x\ wcv)}{Fcm\ \ x\ LHV} \qquad [15]$$

(Bailis *et al.*, 2007).

where $(pci - p)$ = the mass of water in the pot, 4.186 J/g °C = the specific heat of water, $(Tcf - Tci)$ = the change in water temperature, $wcv$ = mass of water evaporated from the pot, 2260 J/g = the latent heat of evaporation of water, $Fcm$ = the mass of fuel consumed during the phase of the test and $LHV$ = the theoretical maximum amount of energy that can be extracted from combustion of moisture free fuel if it's completely combusted and the combustion products are cooled to room temperature but the water produced by the reaction of the fuel bound hydrogen remains in the gas phase (Bailis *et al.*, 2007).

### 3.7.2 Burning rate

Burning rate $(rcb)$ which is the rate of fuel consumption per time. This is a measure of the rate of fuel consumption while bringing water to a boil, calculated by dividing the equivalent fuel consumed and the time of the test (t) in minutes.

$$rcb = fcm\ /\ (tci - tcf) \qquad [16]$$

(Bailis *et al.*, 2007).

### 3.7.3 Specific fuel consumption

Specific fuel consumption ($SCc$) is the fuel required to produce a unit output, boiled water in this case, for cold-start high-power phase. It measures the amount of fuel required to produce one liter of boiling water starting with cold stove.

$$SCc = fcm\,/\,(pcf - p) \quad [17]$$

(Bailis *et al.*, 2007).

### 3.7.4 Fire power

Fire power ($FPc$) the ratio of the fuel energy consumed by the stove per unit time, giving the average power output of the stove (in Watts) during the test phase.

$FPc = fcm\; x\; LHV\,/\,60\; x\; (tci - tcf)$ [18] (Bailis *et al.*, 2007).

## 3.8 Ethanol production Costing

The production cost was calculated and an estimated sales price derived from the production cost. The estimated sales price was compared to the prevailing gasoline and kerosene in order to determine the viability of its use as a fuel.

The production cost determination was based on ethanol requirements if a 10% ethanol 90% gasoline blend was to be used. The 10% blend was chosen as a basis due to the fact that the earlier blending program that collapsed in the 1980's was

10% ethanol and 90% gasoline blend (MoE, 2004). The costing was done based on a litre of the blend (10% ethanol and 90% gasoline).

The best yielding variety was used for the costing purposes and assumed to represent the best choice of maize variety for ethanol production in Kenya. The Maize variety selected was HB625 with an ethanol yield of 917.5 litre/hectare at the silking stage, 1445.5 litres/hectare at the milk stage and 825.04 litres/hectare at the dry maize stage (Table 14).

### 3.8.1 Production cost

Assumption: The maize stalks would be used as a feedstock for an already existing ethanol production plant hence, the cost of investment (both the fixed cost of investment and the working capital) was not determined in this case.

The production cost is a summation of all the operating costs which include variable costs (raw materials and utilities), fixed costs (salaries and wages, administrative costs, depreciation, repairs and maintenance) and general expenses (research and marketing) (Peters and Timmerhaus, 1980; Paul, 1980).

$$Total\ production\ cost\ (TPC) = Variable\ costs + Fixed\ costs + General\ expenses \qquad [19]$$

The TPC was based on data from Agro-Chemical and Food Company (ACFC), Kisumu, Kenya, a local ethanol producing industry. The maize stalk juice was assumed to be similar in property to molasses normally used as feedstock by ACFC, since from analysis the juice constitutes of simple sugars mainly sucrose, glucose and fructose just like molasses (USASC, 2003). The adopted production cost was for the year 2009 as in Table 3. But the cost of molasses in Table 3 was replaced with the cost of maize stalk juice in the case of this study.

**3.8.1.1 Cost of maize stalk juice**

The cost of maize stalk juice was taken as the sum of the cost of buying the maize stalks from farmers and the cost of crushing the stalks to yield the juice. The assumption made here was that the maize stalks were obtained from the conventional maize growing in the country. In Kenya, maize is grown for the grain which is a staple food. The maize stalks which are a by-product of maize farming are mainly used for feeding animals after the maize grain has been separated for mainly human consumption. The cost of the maize stalk when used to feed animals was therefore taken as the opportunity cost for the maize stalks if it were used to make ethanol and this cost was taken as the feedstock cost. The cost was taken as the mean of cost of maize stalks, collected from different farmers through administration of questionnaires (Appendix 9)

The cost of crushing was estimated based on electrical power consumption of the crusher and the prevailing Kenya Power and Lighting company power rates as obtained from literature. The assumptions made were;

1. The main cost of squeezing out juice from the stalks is the energy cost consumed by the crusher.
2. The energy required to squeeze out juice from 1ton maize stalks is equivalent to energy required to squeeze out juice from 1ton sorghum stalks.
3. One hour duration for crushing 1ton of stalks.

For the three roller squeezer used, the consumption of electric power per ton of sorghum stalks is 10.8 kW (UNDP, 1994). Since year 2008 to date, the price of electricity has been averaging at KSh. 12 per kWh (ESA BMO, 2009). This was used to calculate the cost of crushing the stalks.

### 3.8.2 Estimation of selling price per litre of ethanol

The selling price per unit volume of the product was estimated as 120% of the total product cost (Peters and Timmerhaus, 1980). The estimated selling price was then compared with the current market price for petroleum based gasoline.

### 3.8.3 Prevailing market price for gasoline and kerosene

A survey for the pump price for gasoline and kerosene was carried out in Nairobi area. The average price was determined and used as the prevailing market price for the specific fuels.

### 3.8.4 Price of a 10% ethanol and 90% gasoline blend

The price of the 10% ethanol and 90% gasoline blend was calculated as sum of 10% cost of ethanol sale price as determined in section 3.8.2 and 90% of gasoline/kerosene prevailing price as determined in section 3.8.3. This sum obtained was the cost of the E10 ethanol/gasoline blend used for comparison of fuel price between pure gasoline as in the market and the E10 blend, hence indicating the benefit of substituting gasoline with ethanol.

### 3.9 Data management and analysis

Data obtained was entered into Excel spreadsheet then exported to SPSS for statistical analysis. The results were expressed as means and Standard deviations. Comparison of the means between and among different maize varieties was done by ANOVA and post ANOVA tests (www.statsoft.com/textbook/stbasic)

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 General overview

This chapter is divided in five sections each covering a specific study objective. Section 4.2 is covering the results on the maize stalk juice yield. The results for juice yield are presented as millilitres per stalk (ml/stalk) as obtained from crushing of the maize stalks and also as litres per hectare, a computation based on the ml/stalk and the number of stalks per hectare. Section 4.3 covers the results on the sugar content and types of sugars in the maize stalk juice. Section 4.4 covers the ethanol yield obtained after fermentation of the maize stalk juice from the different varieties. The results are presented as %v/v and as litres of ethanol per hectare for each variety. The results for the water boiling test for ethanol in comparison to kerosene using Chinese wick stove are presented in section 4.5. Section 4.6 covers costing for ethanol production and estimated sale price and also the prevailing cost of gasoline and kerosene which were compared to the sale price of ethanol as a fuel. All the results are presented per each maize variety and per each growth stage sampled. The results were averaged and expressed as means±SD.

### 4.2 Maize stalk juice yield for some selected maize varieties growing in Kenya at various growth stages

The juice yield was based on amount of juice per stalk for each variety and each growth stage and on the total area of cultivation. The amount of juice squeezed out varied from variety to variety and also across the three different growth stages as shown in Table 4.1 and Table 4.4. Table 4.1 gives the juice yield in ml/stalk as a mean±SD measured after crushing the maize stalks whereas Table 4.4 gives the juice yield in litres/hectare as computed for a hectare. Table 4.2 and Table 4.3 give the stalk height and stalk weights, some of the maize stalk characteristics that influenced juice yield.

#### 4.2.1 Juice yield in ml/stalk

The stalk juice yield indicated no change in the mean stalk juice yield across the three stages for varieties HB513, PHB30G19, MU03022, DH01, DH02, HB624, HB626, HB628 and HB520. For HB516, there was a significant progressive decrease in the stalk juice yield from the silking stage at 143.33 ml/stalk, the milk stage at 101.67 ml/stalk to 85.83 ml/stalk at the dry stage. The mean stalk juice yield for varieties HB625, MU03017 and PHB30079 significantly increased in the milk stage from the silking stage value and then significantly dropped in the dry stage. The mean stalk juice yield for variety DLC in the silking stage and the milk stage were similar but significantly dropped in the dry stage. For Katumani, there was a significant drop in the mean juice yield across the stages with the highest mean juice yield in the silking stage and the lowest in the dry stage.

**Table 4.1: Juice yield in different maize varieties at different growth stages**

| Maize Variety | Juice yield (ml/stalk) | | |
|---|---|---|---|
| | **Silking stage** | **Milk stage** | **Dry maize stage** |
| **Medium potential zone varieties** | | | |
| HB520 | 85.42±17.96 | 101.67±15.07$^{b}$ | 70.00±17.50$^{b}$ |
| HB513 | 107.78±31.28$^{b}$ | 102.78±16.44$^{b}$ | 113.33±8.04$^{e}$ |
| HB516 | 143.33±12.58$^{Ad}$ | 101.67±7.64$^{b}$ | 85.83±23.76$^{c}$ |
| PHB30G19 | 58.33±18.76 | 77.50±6.61$^{a}$ | 56.67±9.46$^{a}$ |
| MU03022 | 79.17±24.66 | 113.33±34.49$^{b}$ | 84.17±25.04$^{c}$ |
| MU03017 | 45.00±2.50 | 103.33±23.09$^{A\,b}$ | 70.83±3.82$^{b}$ |
| PHB30079 | 51.67±7.64 | 76.67±10.41$^{A\,a}$ | 56.67±5.20$^{a}$ |
| **Dry land varieties** | | | |
| DLC | 68.89±20.09$^{A}$ | 81.67±11.55$^{Aa}$ | 34.33±9.29 |
| Katumani | 29.17±3.82$^{B}$ | 20.42±5.91$^{A}$ | 8.33±1.91 |
| DH01 | 37.92±6.41$^{b}$ | 38.33±8.51 | 30.00±5.45 |
| DH02 | 50.42±10.63 | 43.75±17.72 | 29.17±4.02 |
| **High potential zone varieties** | | | |
| HB614 | 100.00±12.58$^{a}$ | 142.67±12.22$^{Ac}$ | 163.33±13.33$^{Af}$ |
| HB624 | 96.67±19.09$^{a}$ | 98.33±10.41$^{b}$ | 58.33±28.10$^{a}$ |
| HB625 | 124.58±22.09$^{c}$ | 176.67±20.36$^{Ad}$ | 103.33±22.55$^{d}$ |
| HB626 | 145.83±47.74$^{d}$ | 105.00±29.47$^{b}$ | 95.83±8.04$^{c}$ |
| HB628 | 121.25±48.72$^{c}$ | 160.00±30.41$^{d}$ | 89.17±13.77$^{c}$ |

*Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

Comparison of the juice yield in ml/stalk between different varieties was done stage by stage. In the silking stage, the mean stalk juice yield of PHB30G19, MU03022, MU03017, PHB30079, DLC, Katumani, DH02 and HB520 were similar. This group also had the lowest mean stalk juice yield among all the varieties. The mean stalk juice yield of HB516 and that of HB626 were similar and significantly higher at 143.33 ml and 145.83 ml respectively, than for all the other varieties. The highest juice yield per stalk in this stage was for HB626 with 145.83 ml/stalk and the lowest was for Katumani with 29.17 ml/stalk.

In the milk stage, the mean stalk juice yield of Katumani, DH01and DH02 were similar but significantly lower than for the other varieties. The analysis gives the mean stalk juice yield of HB625 and HB628 as significantly higher than all the rest. The highest juice yield in this stage was 176.67 ml/stalk for variety HB625 and the lowest yield in this stage was 20.42 ml/stalk for Katumani.

The analysis of the mean stalk juice yield in dry maize stage indicated no significant difference between DLC, Katumani, DH01 and DH02. The yields here were as low as 8.3 ml/stalk for katumani. It also shows that these mean stalk juice yields were the lowest followed by those of PHB30G19, PHB30079 and HB624. HB614 had a significantly higher mean stalk juice yield than all other varieties at 163.3 ml/stalk.

The dry land varieties had low juice yields per stalk with the minimum being in the dry stage for all of them. Overall, Katumani had the lowest juice yield per stalk with 29.17 ml, 20.42 ml and 8.33ml in the silking, the milk and the dry stages respectively. Corresponding juice yields for variety HB625 were 176.67ml/stalk, 124.38 ml/stalk and 103.3 ml/stalk.

Some of the factors that the juice yield was dependent on were the stalk height and stalk weight. The higher the values of these parameters, the higher was the juice yield per stalk. Stalks with high values of height also depicted high values of stalk weight. The varieties which did not have significant variation of stalk weight across the stages also showed no significant difference of the juice yield across the stage. This trend was repeated in the analysis between the varieties. Varieties with low stalk weights also had low juice yields. Table 4.3 and Table 4.3 respectively show the stalk heights and weights for the different varieties at the three growth stages studied.

Analysis of the mean stalk height across the 3 stages for each variety showed that there was no significant difference in stalk height across the stages for varieties HB513, HB516, PHB30G19, MU03022, PHB30079, DLC, KATUMANI, HB614, HB626 and HB628. At the silking stage, the stalks of DH01 and DH02 were significantly shorter than at the milk stage and dry maize stage but the stalk height for milk stage and dry maize stage were similar. For HB624 and HB625, the silking stage and dry maize stages were similar but significantly different from the milk stage. These results are as indicated in Table 4.2. Sampling for all the varieties studied started at the silking stage. At this stage the maize stalk was assumed to have attained the maximum height and no significant change in height was expected at the consequent growth stages, the maize plant had reached its full height (Williams *et al.*, 1999). Ten out of the sixteen varieties sampled were in agreement with this. The other varieties exhibit a slight increase in the height.

**Table 4.2: Average stalk height in different maize varieties at different growth stages**

| Maize variety | Stalk height (cm) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB513 | $129.07\pm14.04^{a}$ | $144.70\pm10.10^{b}$ | $135.67\pm3.79^{b}$ |
| HB516 | $139.00\pm17.09^{b}$ | $127.33\pm5.13$ | $140.67\pm10.26^{c}$ |
| HB520 | $155.30\pm3.50^{Ad}$ | $127.10\pm7.64$ | $137.00\pm3.61^{c}$ |
| PHB30G19 | $128.00\pm10.39^{a}$ | $135.00\pm13.53^{b}$ | $111.67\pm14.50^{a}$ |
| MU03022 | $118.67\pm12.66$ | $131.33\pm10.69^{a}$ | $125.33\pm8.08^{a}$ |
| MU03017 | $111.00\pm0.00$ | $126.33\pm6.03^{A}$ | $129.67\pm4.93^{Aa}$ |
| PHB30079 | $107.67\pm14.22$ | $122.33\pm4.51$ | $108.67\pm6.11^{a}$ |
| **Dry land varieties** | | | |
| DLC | $95.43\pm6.74$ | $107.43\pm13.04$ | $88.60\pm11.59$ |
| Katumani | $89.37\pm2.77$ | $102.20\pm11.46$ | $90.13\pm6.66$ |
| DH01 | $89.80\pm8.67$ | $120.70\pm2.76^{A}$ | $119.27\pm7.5^{Aa}$ |
| DH02 | $99.33\pm3.62$ | $128.03\pm7.26^{A}$ | $123.20\pm3.2^{Aa}$ |
| **High potential zone varieties** | | | |
| HB614 | $165.33\pm8.50^{e}$ | $169.00\pm13.45^{c}$ | $164.33\pm7.57^{e}$ |
| HB624 | $139.53\pm19.92^{b}$ | $173.93\pm15.52^{Ac}$ | $129.33\pm14.57^{a}$ |
| HB625 | $147.60\pm6.26^{c}$ | $177.53\pm7.07^{Ac}$ | $146.33\pm4.04^{d}$ |
| HB626 | $141.20\pm26.43^{b}$ | $177.00\pm15.22^{c}$ | $143.00\pm4.36^{c}$ |
| HB628 | $139.93\pm12.02^{b}$ | $170.37\pm2.61^{c}$ | $149.33\pm20.60^{d}$ |

*Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

The comparison of the stalk height between the different varieties was done stage by stage. In the silking stage, the varieties MU03022, MU03017, PHB30079, DLC, Katumani, DH01, and DH02 had similar mean stalk height ranging between 89.37cm – 118.67 cm and significantly lower than all the other varieties. The mean height for HB513 and PHB30G19 were similar. The hybrids had significantly higher mean height with HB614 having the highest height of 165.33cm.

In the milk stage, the trend was the same as in the silking stage with varieties HB516, PHB30079, Katumani, MU03017, DLC, DH01, DH02 and HB520 having a mean height that was similar but significantly lower from all other varieties. The mean height of HB614, HB624, HB625, HB626 and HB628 were similar, ranging between 169.0cm and 177.5cm and significantly the highest among all the varieties.

In the dry maize stage, DLC and Katumani had the lowest similar stalk heights, followed by PHB30G19, MU03022, MU03017, PHB30079, DH01, DH02 and HB624 whose means were similar. HB625, HB628 and HB614 had significantly higher mean stalk height than the other varieties. The highest height recorded in this stage was 164.3cm for HB614

Between varieties, the 600 series (HB614, HB625, HB626, and HB628) were observed to have the tallest stalks in all the stages. Their height ranged between 129.3 cm and 177.5 cm. These varieties are tall (www.Kenyaseed.com/maize). The dry land composites (Katumani, DLC, DH01 and DH02) generally had short stalks, the heights ranging between 89.3 cm and 128.0 cm in all the stages. These stalks were drier at the dry stage with very little juice.

Table 4.3 gives the stalk weight results. For stalk weight analysis across the stages, the varieties HB513, HB516, PHB30G19, MU03022, PHB30079, DH01, DH02, HB626, HB628 and HB520 Mean±SD values were similar in their stalk weights. For HB614, the mean stalk weight was significantly greater in the milk stage and the dry maize stage compared to the silking stage. DLC had an increase in the milk stage and a significant decrease in the dry maize stage. For HB624, the mean stalk weight in the silking stage and the milk stage was similar but significantly greater than in the dry maize stage. Katumani had its mean stalk weight decreasing significantly from the silking stage across to the dry stage.

Stalk weight analysis across varieties was done in every stage using one-way Anova. In the silking stage, the mean stalk weight of varieties PHB30G19, MU03022, MU03017, PHB30079, DLC, KATUMANI, DH01 and DH02 were similar. Katumani had the lowest with 0.11 kg/stalk. The values of the means of this group were also the lowest among all the varieties. The analysis also indicated the mean stalk weight of HB626 was the highest and was similar to that of HB625 at 0.42 kg/stalk and 0.41 kg/stalk respectively.

**Table 4.3: Average stalk weight in different maize varieties at different growth stages (kg.)**

| Maize variety | Stalk weight (kg) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | 0.28±0.05$^{a}$ | 0.33±0.06$^{c}$ | 0.30±0.04$^{d}$ |
| HB513 | 0.34±0.05$^{b}$ | 0.35±0.02$^{c}$ | 0.34±0.01$^{e}$ |
| HB516 | 0.35±0.03$^{b}$ | 0.26±0.0$^{b}$ | 0.33±0.04$^{e}$ |
| PHB30G19 | 0.19±0.02 | 0.23±0.01$^{a}$ | 0.22±0.01$^{b}$ |
| MU03022 | 0.22±0.06 | 0.26±0.05$^{b}$ | 0.33±0.06$^{e}$ |
| MU03017 | 0.15±0.01 | 0.27±0.05$^{Ab}$ | 0.28±0.03$^{Ac}$ |
| PHB30079 | 0.18±0.04 | 0.22±0.03$^{a}$ | 0.25±0.03$^{c}$ |
| **Dry land varieties** | | | |
| DLC | 0.23±0.02 | 0.29±0.04$^{Ab}$ | 0.19±0.02$^{Ba}$ |
| KATUMANI | 0.11±0.01$^{B}$ | 0.08±0.01$^{A}$ | 0.05±0.01 |
| DH01 | 0.13±0.02 | 0.16±0.03$^{a}$ | 0.12±0.02$^{a}$ |
| DH02 | 0.16±0.01 | 0.19±0.04$^{a}$ | 0.15±0.01$^{a}$ |
| **High potential zone varieties** | | | |
| HB614 | 0.33±0.03$^{b}$ | 0.40±0.02$^{Ad}$ | 0.54±0.01$^{Bg}$ |
| HB624 | 0.33±0.02$^{Ab}$ | 0.39±0.04$^{Ad}$ | 0.26±0.07$^{c}$ |
| HB625 | 0.41±0.03$^{d}$ | 0.54±0.04$^{Ae}$ | 0.37±0.06$^{f}$ |
| HB626 | 0.42±0.12$^{d}$ | 0.43±0.07$^{d}$ | 0.37±0.05$^{f}$ |
| HB628 | 0.36±0.12$^{c}$ | 0.53±0.06$^{e}$ | 0.36±0.05$^{f}$ |

*Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

In the milk stage, Katumani's mean stalk weight of 0.08 kg/stalk was significantly lower than for all the other varieties. The analysis indicated that the stalk weight of PHB30G19, PHB30079, DH01 and DH02 were similar. Varieties

HB625 and HB628 mean stalk weight were similar but were significantly higher than that of all other varieties with 0.54 kg/stalk and 0.53 kg/stalk respect.

For the dry maize stage, Katumani had a significantly lower mean stalk weight than all the other varieties with 0.05kg/stalk followed by DH01, DH02 and DLC. The means of HB625, HB626 and HB628 were similar and were also among the highest. Variety HB614 with a stalk mean weight of 0.54 kg/stalk had a significantly higher mean stalk weight than all the other varieties.

The stalk weight depended on the stalk height. Majority of the maize varieties which had no significance difference in height across the stages also showed no significant difference in the stalk weight across the stages. The varieties with low stalk heights also had lower weights compared to the tall varieties. This was attributed to the extra height having its related weight which added on to the total weight of the stalk.

The higher the values of stalk height and stalk weight, the higher was the juice yield per stalk. The results of stalk weight in Table 4.3 compares well with the juice yields in Table 4.1. Varieties which did not have significant variation of stalk weight across the stages also showed no significant difference of the juice yield across the stages.

Figure. 4.1: Milk stage (stage 2) of HB513 at KARI – NARL just before sampling.

Figure. 4.2: The stalks of HB513 sampled at milk stage before juice extraction

Figure 4.3: Stalks of HB513 at the dry maize stage (stage 3). The leaves and the cobs are completely dry.

This trend was repeated in the analysis between the varieties. Varieties with low stalk weights also had low juice yields. At the silking stage, variety HB626 had the highest stalk weight of 0.42 kg/stalk and also the highest juice yield of 145.83 ml/stalk. At the milk stage HB625 had the highest stalk weight of 0.54kg and the highest juice yield of 176.67 ml/stalk. This trend repeated at the dry stage where HB614 had the highest stalk weight and juice yield of 0.54 kg/stalk and 163.33 ml/stalk respectively. DH01 and DH02 had short thick stalks and maintained the succulence even in the dry stage hence across all the stages the juice yield was about the same. However Katumani stalks were thin and tended to dry up fast since they lost much of their moisture. This variety had the lowest stalk weight and juice yield in all the stages of growth. The varieties with variation of the juice yield across the stages had the lowest value in the dry stage which was expected since at this stage the stalks had lost significant moisture compared to the green maize stage and silking stage.

The comparison of the juice yield indicated the high potential zone hybrids had high juice content compared to the dry land composites. This was so because of the characteristics of the stalks as illustrated in Table 5 and Table 6.

**4.2.2 Juice yield in litres/hectare**

The juice yield per hectare was related to the juice yield per stalk and the plant population. The plant population for the dry land composites was found to be 74059 stalks per hectare while for the hybrids, was 106640 stalks per hectare based on the spacing used and number of plants per hole (MoA, 2002). The more the stalks, the more the yield of juice per hectare expected.

Comparison of the Mean juice yield between the stages indicated that there was no significant difference in the mean juice yield per hectare for the 3 stages for varieties HB513, DH02, DH01, PH B30G19, MU03022, HB624, HB626, HB628 and HB520. For the varieties MU03017, PHB30079 and HB625, the mean juice yield showed a significant increase in the milk stage from silking stage value then dropped significantly in the dry maize stage. The mean juice yield for Katumani decreased significantly from stage to stage with the lowest being for the dry maize stage ( 616.0 l/ha) and the highest for the silking stage at 1509.3 l/ha, while that for HB614 increased significantly from the silking stage and had the highest mean juice yield per hectare in the dry maize stage with 17417.9 l/ha. The analysis comparing the juice yield in litres per hectare for different maize varieties was done stage by stage as in Table 4.4

In the silking stage, the mean juice yield per hectare for PHB30G19, MU03022, MU03017, PHB30079, DLC, Katumani, DH01 and DH02 were similar and were significantly lower than for all the other varieties. The lowest among them was 2156 litres/hectare for Katumani. The highest mean juice yield per hectare was for HB516 and HB626 with 15285 and 15551.7 litres/ hectare respectively.

In the milk stage, the mean juice yield per hectare for Katumani, DH01 and DH02 were significantly lower than for the other varieties. Still Katumani had the lowest with 1509 litres per hectare. The mean juice yield per hectare for HB516, HB513, PHB30G19, MU03017, PHB30079, HB624, HB626 and HB520 were similar. The mean juice yield per hectare for HB625 and HB628 were similar and significantly higher than for all the other varieties sampled with 18839.7 and 17062.4 litres/ hectare, respectively.

**Table 4.4: Juice yield in different maize varieties at different growth stages (liters/hectare)**

| Maize variety | Juice yield (litres/hectare) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | 9108.83±1914.76$^{a}$ | 10841.73±1606.99$^{b}$ | 7464.80±1866.20$^{a}$ |
| HB513 | 11493.42±3336.15$^{c}$ | 10960.22±1753.48$^{b}$ | 12085.87±857.00$^{c}$ |
| HB516 | 15285.07±1341.86$^{Ae}$ | 10841.73±814.48$^{b}$ | 9153.27±2533.87$^{a}$ |
| PHB30G19 | 6220.67±2000.98 | 8264.60±705.36$^{b}$ | 6042.93±1009.33$^{a}$ |
| MU03022 | 8442.33±2630.21 | 12085.87±3678.05$^{c}$ | 8975.53±2670.44$^{a}$ |
| MU03017 | 4798.80±266.60 | 11019.47±2462.75$^{Ab}$ | 7553.67±407.24$^{a}$ |
| PHB30079 | 5509.73±814.48 | 8175.73±1109.94$^{Ab}$ | 6042.93±554.97$^{a}$ |
| **Dry land varieties** | | | |
| DLC | 5101.86±1488.03$^{A}$ | 6048.18±855.16$^{Aa}$ | 2542.70±146.88 |
| Katumani | 2156.18±282.31 | 1509.32±436.70$^{A}$ | 616.05±141.15$^{B}$ |
| DH01 | 2803.03±474.20 | 2833.83±629.00 | 2217.78±402.79 |
| DH02 | 3727.10±785.92 | 3234.26±1310.10 | 2156.18±297.05 |
| **High potential zone varieties** | | | |
| HB614 | 10664.00±1341.86$^{b}$ | 15213.97±1303.16$^{Ad}$ | 17417.87±1421.87$^{Ad}$ |
| HB624 | 10308.53±2036.19$^{b}$ | 10486.27±1109.94$^{b}$ | 6220.67±2996.53$^{a}$ |
| HB625 | 13285.57±2355.80$^{d}$ | 18839.73±2171.33$^{Ae}$ | 11019.47±2404.33$^{b}$ |
| HB626 | 15551.67±5090.48$^{e}$ | 11197.20±3143.17$^{b}$ | 10219.67±857.00$^{a}$ |
| HB628 | 12930.10±5195.28$^{d}$ | 17062.40±3243.33$^{e}$ | 9508.73±1468.32$^{a}$ |

*Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

In the dry maize stage, more than half of the varieties had no significant difference in their mean juice yield per hectare. These varieties are HB516, PHB30G19, MU03022, MU03017, PHB30079, HB624, HB626, HB628 and HB520. The varieties DLC, Katumani, DH01 and DH02 had similar mean juice yield, ranging between 616.0litres/hectare and 2542.7 litres/hectare, which was significantly lower than for all the other varieties. HB614 had the highest mean juice yield per hectare of 17417.9 litres/ hectare which was significantly different from the others.

The trend for the juice yield per hectare compared well with that of the juice yield per stalk with the dry land composites having significantly low yields and the 600-series hybrids having significantly high yields. The dry land composites (Katumani, DLC, DH01 and DH02) generally had short stalks. These stalks were drier at the dry stage with very little juice. The 600 series Hybrids (614, 624-628) had thick tall stalks and their high juice yield per hectare results was attributed to this and the higher plant population compared to the composites. Majority of the varieties had their juice yield highest at the milk stage. This was expected as at this stage the plant had reached its peak growth and accumulated water in the stalk and drying had not yet set in.

**4.3 Sugar content of maize stalk juice and types of sugar present in the juice**

This section represents the sugar content in the maize stalk juice of the different maize varieties at the three growth stages studied for each of the varieties. The results are represented as $^0$Brix and as % total sugars, a summation of the specific sugars measured. Results of the types of sugars identified present in the juice and their quantities are also tabulated.

### 4.3.1 Sugar content of maize stalk juice in $^0$Brix

The sugar content presented here was in $^0$Brix as measured using a refractometer. This was a quick estimate of the sugars as presented in Table 4.5. The one-way analysis for the sugar content across stages showed no significant variation in the sugar content between the three stages for the varieties MU03022, MU03017, PHB30079, HB614, HB625, HB626 and HB628. The other varieties had significant variations in sugar content across the stages. Variety HB513 had the highest sugar content in the dry stage and the lowest in the milk stage.

For HB516, the sugar content increased significantly from the value in the silking stage all through to dry maize stage. This non-significant difference in the total sugars across the stages in most of the varieties showed little change in the sugars during the periods observed as the plant matured. However the slight decrease in the sugars in the milk stage can be attributed to translocation of sugars from stalks to grains during grain filling (Widstorm, 1988). In the dry stage, the stalks had lost water and this caused concentration of sugars in the remaining juice, hence the higher sugar levels in the dry stage for most of the varieties.

Comparison between the varieties in the silking stage showed that HB520 had significantly the highest sugar content of 13.73 $^0$Brix and HB516, PHB30G19 and MU03022 had the lowest with 8.63, 9.23 and 9.03 $^0$Brix respectively. In the milk stage, KATUMANI, DH01, DH02 had significantly the highest mean sugar content than the other varieties, the highest among them being 15.13 $^0$Brix for DH02.

**Table 4.5: Sugar content ($^0$Brix) in different maize varieties at different growth stages**

| Maize Variety | Sugar content ($^0$Brix) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | 13.73±0.42$^{Ag}$ | 13.00±0.17$^{Ac}$ | 12.03±0.45$^{b}$ |
| HB513 | 10.90±0.20$^{Ac}$ | 8.80±0.36 | 12.17±0.40$^{Bb}$ |
| HB516 | 8.63±0.29 | 9.73±0.06$^{Aa}$ | 12.07±0.84$^{Bb}$ |
| PHB30G19 | 9.23±0.59$^{A}$ | 8.73±0.21 | 10.03±0.45$^{A}$ |
| MU03022 | 9.03±0.42 | 9.37±0.32 | 9.83±1.07 |
| MU03017 | 8.97±0.74 | 9.97±0.12$^{a}$ | 8.87±0.67 |
| PHB30079 | 10.23±0.76$^{b}$ | 9.97±0.45$^{a}$ | 10.03±0.06 |
| **Dry land varieties** | | | |
| DLC | 11.50±0.60$^{Ad}$ | 9.83±0.71$^{a}$ | 12.17±0.40$^{Ab}$ |
| KATUMANI | 10.13±0.15$^{a}$ | 14.20±0.10$^{Be}$ | 11.33±0.21$^{Aa}$ |
| DH01 | 10.07±0.06$^{a}$ | 14.33±0.81$^{Be}$ | 12.33±0.06$^{Ab}$ |
| DH02 | 10.07±0.06$^{a}$ | 15.13±0.83$^{Af}$ | 10.93±0.06$^{a}$ |
| **High potential zone varieties** | | | |
| HB614 | 12.60±0.60$^{f}$ | 10.93±0.15$^{b}$ | 11.50±1.13$^{a}$ |
| HB624 | 13.23±0.31$^{Af}$ | 12.20±0.36$^{c}$ | 13.40±0.56$^{Ac}$ |
| HB625 | 13.00±0.56$^{f}$ | 12.97±0.15$^{c}$ | 13.20±1.61$^{c}$ |
| HB626 | 12.17±0.38$^{e}$ | 13.53±0.49$^{d}$ | 13.77±1.36$^{d}$ |
| HB628 | 12.63±0.67$^{f}$ | 12.57±0.29$^{c}$ | 13.87±0.67$^{d}$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

The varieties MU03022, PHB30G19 and HB513 had similar sugar content which was significantly lower compared to the other varieties. For dry maize stage, PHB30G19, MU03022, MU03017 and PHB30079 had similar mean sugar content which were the lowest among all varieties. In this stage HB626 and HB628 had the highest mean sugar content of 13.77 and 13.87 $^0$Brix respectively. Other than the varieties MU03022 and MU03017, all the other varieties in this stage had sugar content levels above 10 $^0$Brix in all the stages.

Among all the varieties at all the stages of growth, the range of sugars was between 8.63 $^0$Brix and 15.13 $^0$Brix. The medium potential zone varieties had low sugars compared to the dry land and high potential varieties whose sugar content was ranging between 10 $^0$Brix and 15 $^0$Brix. The levels of sugar content for the maize stalks studied here compared to sugar levels of sorghum bred for ethanol production which range between 11 $^0$Brix and 20 $^0$Brix (UNDP, 1994). The high potential zone varieties maintained high sugar levels through the three growth stages.

### 4.3.2 Specific sugars (glucose, fructose and sucrose) in maize stalk juice

The results presented here are the types and quantities of the main sugars present in the maize stalk juice as analyzed using the HPLC system.

#### 4.3.2.1 Types of specific sugars in maize stalk juice

The samples prepared from the maize stalk juices gave three distinct peaks upon running in the HPLC machine. Sample peak given for DH01 (Appendix E). The retention times for these peaks were on average 9.4 minutes, 11.3 minutes and 16.1 minutes for the first, second and third peaks respectively. These peaks had the retention times similar to the three standard sugars (fructose, glucose and sucrose) confirming that the main sugars in the maize stalk juice are fructose, glucose and sucrose. The standard sugars ran in this study gave retention time as 9.3 minutes, 11.2 minutes and 15.9 minutes for fructose, glucose and sucrose respectively (Appendix F). Hence, the sugars identified in the maize stalk juice of the varieties sampled were sucrose, fructose and glucose. This agrees with research conducted at the University of Illinois on tropical maize stalk juice (SD, 2007), which indicates sucrose, glucose and fructose as the main sugars in tropical maize stalks. This also compares with the sorghum stalks juice which contains the three sugars as the main sugars (UNDP, 1994).This was the case with all the maize varieties sampled and at all the stages of sampling.

**4.3.2.2 Quantity of fructose, glucose and sucrose in maize stalk juice**

The plot of the standard sugars' concentrations against the peak areas from the chromatograms for each sugar gave the standard curves as presented in Appendix G. These curves gave the standard equation for each sugar which was used to estimate the concentration of similar sugars present in the maize stalk juice. The values of the constants for the equation obtained from the standard curves and used to calculate the specific sugar concentrations in the juice were;

y = area of peak (as got directly from the plot of the chromatograms)

m = a constant

= 58584 for Sucrose, 56333 for Fructose and 46614 for Glucose

c = constant

= 11949 for Sucrose, 13051 for Fructose and 17476 for glucose

The values calculated for the concentration of each sugar in the juice are as tabulated in Table 4.6, Table 4.7 and Table 4.8.

The analysis of the mean fructose content for each variety across the stages indicated similar mean values between the stages for varieties MU03017, PHB30079 and DLC. For all the other varieties there was a significant difference in the mean fructose content between the stages with the highest being in the silking stage and the lowest in the dry maize stage for all the varieties. This is illustrated in Table 4.6.

Comparison of the levels of fructose in the silking stage for all the varieties gave Katumani, DH02, and HB614 the lowest value which was significantly different from the other varieties.

**Table 4.6: Fructose concentration in different maize varieties at different growth stages (%)**

| Maize variety | Fructose concentration (%) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | $3.53\pm0.24^{Bb}$ | $1.06\pm0.03^{A}$ | $0.40\pm0.00$ |
| HB513 | $3.50\pm0.00^{Ab}$ | $0.77\pm0.08$ | $0.77\pm0.08$ |
| HB516 | $3.55\pm0.32^{Ab}$ | $3.75\pm0.01^{Ac}$ | $1.66\pm0.02^{b}$ |
| PHB30G19 | $4.99\pm0.11^{d}$ | $3.45\pm0.56^{c}$ | $1.42\pm0.01^{aB}$ |
| MU03022 | $4.37\pm0.11^{Ae}$ | $5.72\pm0.13^{Bd}$ | $1.82\pm0.33^{c}$ |
| MU03017 | $4.30\pm0.11^{c}$ | $2.39\pm0.22^{b}$ | $2.76\pm0.76^{d}$ |
| PHB30079 | $3.96\pm0.23^{c}$ | $3.34\pm0.90^{c}$ | $2.59\pm0.00^{d}$ |
| **Dry land varieties** | | | |
| DLC | $2.74\pm0.37^{a}$ | $2.02\pm0.20^{a}$ | $2.02\pm0.09^{c}$ |
| KATUMANI | $1.98\pm0.09^{B}$ | $1.22\pm0.03^{A}$ | $0.55\pm0.14$ |
| DH01 | $2.91\pm0.04^{Ab}$ | $1.36\pm0.10^{A}$ | $0.87\pm0.23$ |
| DH02 | $1.87\pm0.51^{A}$ | $2.04\pm0.11^{Aa}$ | $0.60\pm0.00$ |
| **High potential zone varieties** | | | |
| HB614 | $1.55\pm0.25^{A}$ | $1.54\pm0.03^{A}$ | $0.92\pm0.01$ |
| HB624 | $3.94\pm0.36^{Ac}$ | $0.73\pm0.45$ | $0.40\pm0.01$ |
| HB625 | $2.94\pm0.20^{Aa}$ | $1.17\pm0.49$ | $0.40\pm0.03$ |
| HB626 | $3.50\pm0.01^{Bb}$ | $1.08\pm0.00^{A}$ | $0.40\pm0.01$ |
| HB628 | $3.93\pm0.08^{Ac}$ | $1.18\pm0.16$ | $1.10\pm0.14$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

Their values ranged from 1.55% to 1.98%. PHB30G19 had the highest mean fructose content of 4.99%. In the milk stage, the mean fructose level for varieties HB513, Katumani, DH01, HB614, HB624, HB625, HB626, HB628 and HB520 were similar and the lowest among all the varieties in this stage. Variety MU03022 had significantly the highest mean of 5.72%. In the dry maize stage, the means of HB513, KATUMANI, DH01, DH02, HB614, HB624, HB625, HB626, HB628 and HB520 are significantly lower compared to the other varieties. The means of MU03017 and PHB30079 were significantly the highest compared to all other varieties. The fructose content was lowest among the three growth stages for all the varieties. The lowest level was 0.4% for varieties HB520, HB624 and HBHB625.

One-way Anova analysis for the mean glucose levels across the stages for each variety showed that all varieties had the lowest mean values of glucose at the dry maize stage, and the highest at the silking stage except for variety PHB30079 which had no significant difference in the means across the three stages (Table 4.7)

Comparison between the different varieties in the silking stage showed that varieties DH02, HB614 and Katumani had significantly the lowest mean glucose content and PHB30G19 had significantly the highest. In the milk stage, varieties HB513, Katumani, DH01, HB614, HB624, HB625, HB626, HB628 and HB520 had similar mean glucose levels but significantly the lowest compared to the other varieties while MU03022 had significantly the highest mean glucose levels. In the dry maize stage, HB513, Katumani, DH01, DH02, HB624, HB625, HB626 and HB520 varieties had the lowest mean glucose levels while the highest mean glucose level was in variety MU03017.

**Table 4.7: Glucose concentration in different maize varieties at different growth stages (%)**

| Maize variety | Glucose concentration (%) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | $4.66 \pm 0.60^{A b}$ | $1.29 \pm 0.20$ | $0.70 \pm 0.03$ |
| HB513 | $3.94 \pm 0.01^{Ab}$ | $0.93 \pm 0.23$ | $0.93 \pm 0.23$ |
| HB516 | $4.49 \pm 0.12^{Ab}$ | $4.47 \pm 0.02^{Ac}$ | $2.53 \pm 0.05^{c}$ |
| PHB30G19 | $5.82 \pm 0.56^{Ad}$ | $4.21 \pm 0.86^{Ac}$ | $1.64 \pm 0.22^{b}$ |
| MU03022 | $4.50 \pm 0.04^{Ab}$ | $6.48 \pm 0.09^{Bd}$ | $2.31 \pm 0.59^{c}$ |
| MU03017 | $5.08 \pm 0.51^{Ac}$ | $2.79 \pm 0.08^{b}$ | $3.46 \pm 0.44^{d}$ |
| PHB30079 | $4.82 \pm 0.44^{b}$ | $4.05 \pm 0.94^{c}$ | $2.49 \pm 0.01^{c}$ |
| **Dry land varieties** | | | |
| DLC | $3.46 \pm 0.31^{Aa}$ | $2.69 \pm 0.23^{b}$ | $2.52 \pm 0.03^{c}$ |
| KATUMANI | $2.38 \pm 0.07^{B}$ | $1.79 \pm 0.14^{A}$ | $0.60 \pm 0.00$ |
| DH01 | $3.49 \pm 0.08^{aB}$ | $1.86 \pm 0.06^{A}$ | $1.16 \pm 0.10$ |
| DH02 | $2.10 \pm 0.58^{A}$ | $2.47 \pm 0.03^{Aa}$ | $0.80 \pm 0.05$ |
| **High potential zone varieties** | | | |
| HB614 | $1.89 \pm 0.09^{A}$ | $1.81 \pm 0.11^{A}$ | $1.40 \pm 0.13^{a}$ |
| HB624 | $4.66 \pm 0.93^{A b}$ | $0.96 \pm 0.49$ | $070 \pm 0.01$ |
| HB625 | $3.40 \pm 0.40^{Aa}$ | $1.18 \pm 0.09$ | $0.70 \pm 0.03$ |
| HB626 | $4.17 \pm 0.06^{Bb}$ | $1.67 \pm 0.12^{A}$ | $0.70 \pm 0.01$ |
| HB628 | $4.19 \pm 0.55^{Ab}$ | $1.59 \pm 0.18$ | $1.40 \pm 0.00^{a}$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

**Table 4.8: Sucrose concentration in different maize varieties at different growth stages (%)**

| Maize variety | Sucrose concentration (%) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | $5.70 \pm 0.55^{e}$ | $7.00 \pm 3.20^{b}$ | $8.85 \pm 0.07^{d}$ |
| HB513 | $4.16 \pm 0.00^{d}$ | $5.47 \pm 0.19^{Ab}$ | $5.47 \pm 0.19^{Aa}$ |
| HB516 | $0.00 \pm 0.01$ | $1.00 \pm 0.01^{A}$ | $5.01 \pm 0.34^{B}$ |
| PHB30G19 | $0.01 \pm 0.00$ | $0.39 \pm 0.08$ | $4.49 \pm 0.48^{A}$ |
| MU03022 | $0.16 \pm 0.01$ | $0.29 \pm 0.03$ | $5.73 \pm 0.48^{Aa}$ |
| MU03017 | $0.38 \pm 0.06$ | $3.95 \pm 0.08^{Aa}$ | $3.29 \pm 0.39^{A}$ |
| PHB30079 | $0.20 \pm 0.07$ | $0.89 \pm 0.27$ | $3.31 \pm 0.00^{A}$ |
| **Dry land varieties** | | | |
| DLC | $7.38 \pm 0.02^{Af}$ | $4.67 \pm 0.16^{b}$ | $4.61 \pm 0.03$ |
| KATUMANI | $3.57 \pm 0.90^{c}$ | $6.93 \pm 0.40^{b}$ | $6.74 \pm 1.01^{b}$ |
| DH01 | $2.21 \pm 0.15^{a}$ | $5.06 \pm 1.57^{Ab}$ | $6.48 \pm 0.33^{aB}$ |
| DH02 | $1.35 \pm 0.22$ | $6.65 \pm 0.66^{Ab}$ | $7.47 \pm 1.76^{Ac}$ |
| **High potential zone varieties** | | | |
| HB614 | $7.51 \pm 1.30^{f}$ | $3.85 \pm 0.64^{a}$ | $5.80 \pm 0.97^{a}$ |
| HB624 | $3.48 \pm 0.31^{c}$ | $5.32 \pm 0.77^{Ab}$ | $9.20 \pm 0.14^{Bd}$ |
| HB625 | $2.26 \pm 0.06^{a}$ | $5.55 \pm 2.33^{b}$ | $11.70 \pm 0.01^{Af}$ |
| HB626 | $4.40 \pm 0.01^{d}$ | $7.12 \pm 0.00^{Ab}$ | $10.15 \pm 0.07^{Be}$ |
| HB628 | $2.79 \pm 0.23^{b}$ | $9.25 \pm 0.41^{Ac}$ | $8.60 \pm 0.14^{Ad}$ |

*Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others increasing in alphabetical order.

One-way analysis for the mean sucrose levels in each variety across the stages indicated the silking stage as having significantly the lowest mean sucrose content and the dry maize stage as having significantly the highest for many of the varieties other than for Katumani, HB614 and HB520 whose mean sucrose content was not significantly different across the three stages.

Comparison between varieties in the silking stage indicated similar mean sucrose levels of varieties HB516, PHB30G19, MU03022, MU03017 PHB30079 and DH02 which were significantly the lowest among all the varieties. Varieties HB614 and DLC had significantly the highest mean sucrose content in this stage with 7.51% and 7.38% respectively. In the milk stage, the lowest mean indicated is for varieties HB516, PHB30G19, MU03022 and PHB30079 with less than 1% and the highest is for HB628 with 9.25%. For the dry maize stage, HB516, PHB30G19, MU03017, PHB30079 and DLC had significantly the lowest mean while HB625 had the highest with 11.70%.

The trend for the specific sugars (fructose, glucose and sucrose) that was observed was a significant decrease for the fructose and glucose levels across the stages, silking stage having the highest in majority of the varieties. The levels of sucrose were increasing with the silking stage having the lowest sucrose content and the highest being in the dry stage for all the varieties. This indicated bonding of glucose and fructose as the plant matured to yield sucrose. This trend of the sugars compares with that of sorghum whose sucrose levels in the stalk increases as the plant matures (UNDP, 1994). A study by Glasziou (1961), also show the same trend for the transformation of the sugars in the stalks of sugarcane. According to this study, as the storage tissue in the cane matures, there is a marked increase in the sucrose content and a concomitant decrease in the glucose and fructose.

**4.3.3 % Total sugars in maize stalk juice**

The summation of the three specific sugars (sucrose, glucose and fructose) gave the total % sugar content. (Walter, 1992, Bartolome *et al*., 1996).

As presented in Table 4.9, Anova across the stages shows the sugar content of varieties HB516, PHB30G19, MUO3017, PHB30079, Katumani, DH01, HB614, HB628 and HB520 does not vary much with the stage of growth. There was no significant difference across the stages. For the varieties HB513 and DLC the sugar levels were highest at the silking stage at 11.6% and 13.6% respectively and was the same for the milk and dry maize stage. Variety MU03022 had a significantly high sugar content of 12.5% at the milk stage compared to the other stages. Variety HB625 had the highest sugar content in the dry stage while HB626 had high sugar content both in the silking and dry maize stage.

Comparison of the % total sugars present in the juice of different maize varieties was done per every stage of growth.

**Table 4.9: Total sugar content (% sugars) in different maize varieties at different growth stage**

| Maize variety | Total sugars (%) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | 13.89±1.39$^{e}$ | 9.35±3.38 | 9.94±0.05 |
| HB513 | 11.60±0.01$^{Ab}$ | 7.17±0.34 | 7.17±0.34 |
| HB516 | 8.05±0.44$^{a}$ | 9.23±0.00 | 9.21±0.42 |
| PHB30G19 | 10.82±0.62$^{a}$ | 8.06±1.49 | 7.55±0.71 |
| MU03022 | 9.04±0.17$^{a}$ | 12.50±0.20$^{Ab}$ | 9.86±1.40 |
| MU03017 | 9.76±0.56$^{a}$ | 9.13±0.22 | 9.51±1.60 |
| PHB30079 | 8.98±0.94$^{a}$ | 8.28±2.10 | 8.38±0.01 |
| **Dry land varieties** | | | |
| DLC | 13.57±0.03$^{Ad}$ | 9.38±0.59 | 9.14±0.03 |
| KATUMANI | 7.93±1.05$^{a}$ | 9.93±0.23 | 7.90±0.86 |
| DH01 | 8.61±0.27$^{a}$ | 8.29±1.53 | 8.50±0.01 |
| DH02 | 5.32±1.31 | 11.16±0.57$^{Aa}$ | 8.88±1.72A$^{A}$ |
| **High potential zone varieties** | | | |
| HB614 | 10.96±1.64$^{a}$ | 7.20±0.71 | 8.12±0.84 |
| HB624 | 12.09±1.60$^{Ac}$ | 7.01±0.81 | 10.29±0.14$^{Aa}$ |
| HB625 | 8.60±0.27$^{a}$ | 7.90±1.93 | 12.80±0.01$^{Ac}$ |
| HB626 | 12.06±0.06$^{Bc}$ | 9.87±0.12 | 11.25±0.07$^{Ab}$ |
| HB628 | 10.91±0.70$^{a}$ | 12.02±0.42$^{a}$ | 11.10±0.29$^{b}$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

At the silking stage, varieties HB520 and DLC had the highest levels of % sugars with 13.9 % and 13.6% respectively. Variety DH02 had the lowest with 5.3%. At the milk stage, the varieties which had the highest sugar levels have their sugar levels drop to around 9% and this is maintained at that level even in the dry stage. Varieties MU03022 and HB628 had the highest levels of sugar in the milk stage with 12.5% and 12.0% respectively. The sugar content of DH02 rose sharply in the milk stage to 11.2%. In the milk stage most of the varieties had the sugar content level ranging between 7% and 9%. In the dry maize stage HB625 had the highest sugar content at 12.8%. The variety with the lowest level was HB513 with 7.2%. Most of the 600 series varieties had the sugar content level above 10%.

The comparison of $^{0}$Brix and the % total sugars for the three stages shown in Table 4.10 was analyzed using the t-test. In silking stage, 6 varieties out of the 16 studied varieties had a significant difference in their mean sugar content. In the milk and dry maize stages, 11 of the sixteen varieties sampled had a significant difference in their mean sugar content. The trend observed was a higher $^{0}$Brix than the % total sugars in most of the varieties in all the three stages. This was expected because the % total was a summation of the three main sugars present in the juice without considering other sugars whose concentration was very low and insignificant whereas the Brix method measured all sugars present in the juice.

**Table 4.10: Comparison of the $^{0}$Brix and %Total Sugars in different maize varieties at different growth stages**

| Maize Variety | Silking stage | | | Milk stage | | | Dry maize stage | | |
|---|---|---|---|---|---|---|---|---|---|
| | $^{0}$Brix | % Total sugars | $t_{cal}$ | $^{0}$Brix | % Total sugars | $t_{cal}$ | $^{0}$Brix | % Total sugars | $t_{cal}$ |
| **Medium potential zone varieties** | | | | | | | | | |
| HB520 | 13.73±0.42 | 13.89±1.39 | 0.20 | 13.00±0.17 | 9.35±3.38 | 2.05 | 12.03±0.45 | 9.94±0.05 | 6.20 |
| HB513 | 10.90±0.20 | 11.60±0.01 | 4.69 | 8.80±0.36 | 7.17±0.34 | 5.04 | 12.17±0.40 | 7.17±0.34 | 14.23 |
| HB516 | 8.63±0.29 | 8.05±0.44 | 1.85 | 9.73±0.06 | 9.23±0.00 | 11.67 | 12.07±0.84 | 9.21±0.42 | 4.32 |
| PHB30G19 | 9.23±0.59 | 10.82±0.62 | 2.91 | 8.73±0.21 | 8.06±1.49 | 0.84 | 10.03±0.45 | 7.55±0.71 | 4.94 |
| MU03022 | 9.03±0.42 | 9.04±0.17 | 0.01 | 9.37±0.32 | 12.50±0.20 | 11.97 | 9.83±1.07 | 9.86±1.40 | 0.02 |
| MU03017 | 8.97±0.74 | 9.76±0.56 | 1.28 | 9.97±0.12 | 9.13±0.22 | 5.80 | 8.87±0.67 | 9.51±1.60 | 0.66 |
| PHB30079 | 10.23±0.76 | 8.98±0.94 | 1.68 | 9.97±0.45 | 8.28±2.10 | 1.46 | 10.03±0.06 | 8.38±0.01 | 38.23 |
| **Dry land varieties** | | | | | | | | | |
| DLC | 11.50±0.60 | 13.57±0.03 | 4.64 | 9.83±0.71 | 9.38±0.59 | 0.74 | 12.17±0.40 | 9.14±0.03 | 3.90 |
| Katumani | 10.13±0.15 | 7.93±1.05 | 3.90 | 14.20±0.10 | 9.93±0.23 | 29.56 | 11.33±0.21 | 7.90±0.86 | 7.18 |
| DH01 | 10.07±0.06 | 8.61±0.27 | 9.96 | 14.33±0.81 | 8.29±1.53 | 5.99 | 12.33±0.06 | 8.50±0.01 | 88.78 |
| DH02 | 10.07±0.06 | 5.32±1.31 | 6.88 | 15.13±0.83 | 11.16±0.57 | 5.76 | 10.93±0.06 | 8.88±1.72 | 2.27 |
| **High potential zone varieties** | | | | | | | | | |
| HB614 | 12.60±0.60 | 10.96±1.64 | 1.69 | 10.93±0.15 | 7.20±0.71 | 9.50 | 11.50±1.13 | 8.12±0.84 | 3.56 |
| HB624 | 13.23±0.31 | 12.09±1.60 | 1.31 | 12.20±0.36 | 7.01±0.81 | 10.33 | 13.40±0.56 | 10.29±0.14 | 7.35 |
| HB625 | 13.00±0.56 | 8.60±0.27 | 10.04 | 12.97±0.15 | 7.90±1.93 | 4.95 | 13.20±1.61 | 12.80±0.01 | 0.33 |
| HB626 | 12.17±0.38 | 12.06±0.06 | 0.36 | 13.53±0.49 | 9.87±0.12 | 9.83 | 13.77±1.36 | 11.25±0.07 | 2.49 |
| HB628 | 12.63±0.67 | 10.91±0.70 | 0.85 | 12.57±0.29 | 12.02±0.42 | 1.78 | 13.87±0.67 | 11.10±0.29 | 5.34 |

(Mean values with t-calculated >3.18 are significantly different at $\alpha$=3.18 and df= 3

## 4.4 Ethanol yield from fermentation of maize stalk juice

This section covers the results of ethanol yield in % v/v (Table 4.11) obtained from fermentation of the maize stalk juice and the results of the ethanol yield computed per unit of cultivation area (hectare) in litres per hectare (Table 4.12).

### 4.4.1 Ethanol yield from maize stalk juice in % v/v

**Table 4.11: Ethanol yield in different maize varieties at different growth stages**

| Maize Variety | Ethanol yield ((% v/v) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | $8.78 \pm 0.08^{k}$ | $6.70 \pm 0.10^{Ae}$ | $6.88 \pm 0.15^{Ae}$ |
| HB513 | $5.48 \pm 0.11^{d}$ | $4.42 \pm 0.22^{A}$ | $5.12 \pm 0.04^{Bb}$ |
| HB516 | $4.40 \pm 0.11^{b}$ | $5.36 \pm 0.16^{Ab}$ | $5.84 \pm 0.17^{Bc}$ |
| PHB30G19 | $3.22 \pm 0.0$ | $5.33 \pm 0.41^{Ab}$ | $3.37 \pm 0.20$ |
| MU03022 | $4.19 \pm 0.11^{a}$ | $4.77 \pm 0.04^{A}$ | $4.23 \pm 0.30^{a}$ |
| MU03017 | $4.08 \pm 0.14^{Aa}$ | $4.98 \pm 0.04^{Ba}$ | $3.46 \pm 0.16$ |
| PHB30079 | $4.77 \pm 0.04^{Ac}$ | $5.33 \pm 0.41^{B b}$ | $3.44 \pm 0.15$ |
| **Dry land varieties** | | | |
| DLC | $5.90 \pm 0.10^{Bf}$ | $4.60 \pm 0.20$ | $5.10 \pm 0.10^{Ab}$ |
| KATUMANI | $5.71 \pm 0.03^{Ae}$ | $8.93 \pm 0.04^{h}$ | $6.9 \pm 0.01^{Be}$ |
| DH01 | $6.84 \pm 0.03^{Ag}$ | $8.10 \pm 0.26^{Bg}$ | $6.41 \pm 0.04^{d}$ |
| DH02 | $5.37 \pm 0.11^{g}$ | $8.65 \pm 0.04^{A h}$ | $5.20 \pm 0.14^{Bb}$ |
| **High potential zone varieties** | | | |
| HB614 | $6.70 \pm 0.18^{Bg}$ | $4.94 \pm 0.19^{a}$ | $5.83 \pm 0.05^{Ac}$ |
| HB624 | $8.01 \pm 0.08^{Bh}$ | $6.27 \pm 0.06^{c}$ | $7.00 \pm 0.05^{Ae}$ |
| HB625 | $6.91 \pm 0.04^{g}$ | $7.67 \pm 0.07^{Af}$ | $7.50 \pm 0.20^{Af}$ |
| HB626 | $8.27 \pm 0.06^{Bj}$ | $6.55 \pm 0.13^{d}$ | $7.46 \pm 0.17^{Af}$ |
| HB628 | $6.77 \pm 0.04^{Ag}$ | $5.98 \pm 0.07^{c}$ | $7.12 \pm 0.09^{Be}$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

The fermentation was complete within the first 24 hours in all the samples fermented. The sugar levels dropped significantly within this period and remained stable after the 24 hours giving a constant sugar reading for subsequent readings. Same fermentation conditions were observed for all the samples for the different maize varieties at the three different sampling stages.

One-way analysis across stages indicated a significant difference in the mean ethanol yields at all stages in most of the varieties. For comparison between different varieties, in the silking stage, PHB30G19 had significantly the lowest mean ethanol yield of 3.2% (v/v) from all other varieties while HB520 had the highest mean with 8.8% (v/v)

In the milk stage, the mean ethanol yield (%v/v) for varieties HB513, MU03022 and DLC were similar but significantly lower than for all the other varieties. DH02 and KATUMANI had the highest ethanol yield (%v/v) in this stage with 8.7 % (v/v) and 8.9% (v/v) respectively.

In the dry stage, the mean (%v/v) ethanol yield for PHB30G19, MU03017 and PHB30079 was similar but significantly lower than all the other varieties. The mean (%v/v) ethanol yield for HB625 and HB626 was similar and the highest in this stage at 7.5% (v/v).

The ethanol yield (%v/v) is related to the sugar content (Paul, 1980; UNDP, 1994)). Sugars are broken down to ethanol and carbon dioxide by enzymes during fermentation and the higher the amount of sugars the higher the amount of ethanol obtained. Those varieties and stages with high sugar levels (in Table 4.9) also had high % (v/v) ethanol yield indicating the relationship of the ethanol yield in % (v/v) to the sugar amount in the juice fermented. The medium potential zone maize varieties had low ethanol yield % (v/v) compared to the dry land and high potential zone maize varieties. Normally, a fermentation starting with sugar concentration of 10% to 12% will yield 5% (v/v) to 6% (v/v) ethanol (Paul, 1980). The dry land and high potential zone maize varieties' ethanol yield results agreed with this. The sugar content for these varieties in all stages ranged from7.0% to 13.6% and the ethanol yield was ranging between 4.6% (v/v) to 8.7% (v/v).

### 4.4.2 Ethanol yield in litres per hectare

The assumption made while computing the ethanol yield per given area of cultivation was that the density of the maize stalk juice was equivalent to that of water. The ethanol yield per cultivation area (Hectare) was dependent on the juice yield and the ethanol yield obtained in % (v/v).

These results were as presented in Table 4.12.

**Table 4.12: Ethanol yield in different maize varieties at different growth stages (liters /hectare)**

| Maize variety | Ethanol yield (liters /hectare) | | |
|---|---|---|---|
| | Silking stage | Milk stage | Dry maize stage |
| **Medium potential zone varieties** | | | |
| HB520 | $800.44\pm174.40^{d}$ | $727.06\pm118.32^{c}$ | $513.08\pm125.75^{b}$ |
| HB513 | $629.45\pm183.40^{b}$ | $484.83\pm80.07^{a}$ | $618.40\pm44.08^{b}$ |
| HB516 | $673.98\pm74.88^{b}$ | $580.74\pm39.61^{b}$ | $535.78\pm154.65^{b}$ |
| PHB30G19 | $201.24\pm68.85^{a}$ | $441.62\pm61.63^{A}$ | $204.62\pm45.50$ |
| MU03022 | $355.52\pm119.21^{a}$ | $576.32\pm176.25^{b}$ | $375.20\pm88.74$ |
| MU03017 | $196.04\pm17.60^{a}$ | $547.88\pm118.62^{A\,b}$ | $261.64\pm24.19$ |
| PHB30079 | $262.74\pm40.16^{a}$ | $433.01\pm27.78^{A}$ | $208.40\pm27.97$ |
| **Dry land varieties** | | | |
| DLC | $301.59\pm91.68^{A\,a}$ | $277.23\pm30.43^{A}$ | $130.05\pm42.58$ |
| KATUMANI | $131.93\pm8.12$ | $156.68\pm11.04^{A}$ | $42.12\pm2.08^{B}$ |
| DH01 | $191.79\pm33.10^{a}$ | $228.91\pm48.65$ | $150.95\pm28.32$ |
| DH02 | $176.05\pm6.82^{a}$ | $324.02\pm120.28$ | $117.96\pm20.19$ |
| **High potential zone varieties** | | | |
| HB614 | $716.41\pm108.26^{c}$ | $751.57\pm71.05^{c}$ | $1016.18\pm85.57^{Af}$ |
| HB624 | $824.69\pm155.20^{d}$ | $657.06\pm63.36^{c}$ | $434.37\pm207.23^{a}$ |
| HB625 | $917.46\pm157.57^{d}$ | $1445.50\pm173.35^{A\,e}$ | $825.04\pm169.70^{e}$ |
| HB626 | $1286.79\pm425.25^{e}$ | $731.03\pm191.06^{c}$ | $763.27\pm80.94^{d}$ |
| HB628 | $873.50\pm345.34^{d}$ | $1018.34\pm181.39^{d}$ | $676.49\pm95.60^{c}$ |

Mean±SD followed by same small letter within the same column are not significantly different and Mean±SD followed by the same capital letter within the same row are not significantly different at 95% confidence limit. Within the row, the Mean±SD without a capital letter superscript is the lowest value followed by the others increasing in alphabetical order. Within the column, the Mean±SD without a small letter superscript is the lowest value followed by the others, increasing in alphabetical order.

0ne-way ANOVA analysis for the mean ethanol yield per hectare across the three growth stages indicated no significant difference in the ethanol yield per hectare across the three stages for the varieties HB516, MU03022, DH01, DH02, HB624, HB626, HB628, HB520 and H513. For PHB30G19, MU03017, PHB30079 and HB625, the mean ethanol yield per hectare in the milk stage was significantly higher than in the silking stage and the dry maize stage but there was no significant difference between mean ethanol yield in the silking stage and the dry maize stage. For DLC, the dry maize stage mean ethanol yield per hectare of 130 litres/hectare was significantly less than the mean values in the silking stage (277.2 litres/hectare) and the milk stage at 301.6 litres/hectare. The mean ethanol yield per hectare for Katumani increased significantly in the milk stage at 156.7 litres/hectare from the mean value of 131.9 litres/hectare in the silking stage, and then dropped significantly to 42.1 litres/hectare in the dry maize stage.

Comparison between the different varieties stage by stage showed that in the silking stage, the varieties PHB30G19, MU03022, MU03017, PHB30079, DLC, DH01 and DH02 had similar mean ethanol yield per hectare, which was the lowest after Katumani, compared to all the other varieties. The variety Katumani had the lowest yield with 131.9 liters/ hectare. The varieties HB624, HB625, HB628 and HB520 also had similar mean ethanol yield per hectare. Variety HB626 had the highest mean ethanol yield per hectare in this stage with 1286.79 liters per hectare. In the milk stage, the highest mean ethanol yield per hectare was for HB625 at 1445.50 liters per hectare while the varieties PHB30079, DLC, Katumani, DH01, DH02 and PHB30G19 had significantly lower mean ethanol yield per hectare than all the other varieties. In the dry maize stage, PHB30G19, MU03022, MU03017, PHB30079, DLC, Katumani, DH01, and DH02 had similar mean ethanol yield per hectare which was significantly lower than for all the other varieties. Variety HB614 had the highest mean ethanol yield per hectare with 1016.18 liters per hectare. Variety HB625 had 825.04 liters per hectare. Most of the varieties had the lowest yield of ethanol per hectare in the dry stage. This compares to the juice yield (litres per hectare) (Table 4.4) which had the same trend.

The ethanol yield per cultivation area (Hectare) is dependent on the juice yield and ethanol yield in %v/v. Despite the dry land composites having higher % (v/v) ethanol yield than the Hybrids, the reverse was true for ethanol yield in Liters/ Hectare because of the high juice yield for the hybrids. The juice yield seemed to be the key determining factor for the ethanol yield in liters per hectare. This was supported by the results obtained for the highest ethanol yielding varieties. Variety HB626 had the highest juice yield (15551.7 litres per hectare) in the silking stage and consequently had the highest ethanol yield in this stage at 1286.8 litres per hectare. The variety Katumani had the lowest juice yield per hectare and the lowest ethanol yield per hectare in the silking stage at 2156.2 liters per hectare and 131.9litres per hectare respectively. In the milk stage the variety HB625 had the highest juice yield and the highest ethanol yield at 18839.7 litres per hectare and 1445.5 litres per hectare respectively. Variety katumani despite having a very high sugar level of 14.2 $^{0}$Brix in the milk stage had the lowest ethanol yield of 156.7 liters per hectare due to the low juice yield. This observation was also seen in the dry maize stage where the variety HB614 yielded the highest juice in liters per hectare and also the highest ethanol yield liters per hectare. In the dry stage Katumani had the lowest juice and ethanol yields at 616 and 42.1liters per hectare, respectively.

The graphs in figures 4.4, 4.5 and 4.6 summarize the trends of the juice yield, the sugar content and related ethanol yield respectively from the maize stalk juice for the various maize varieties studied.

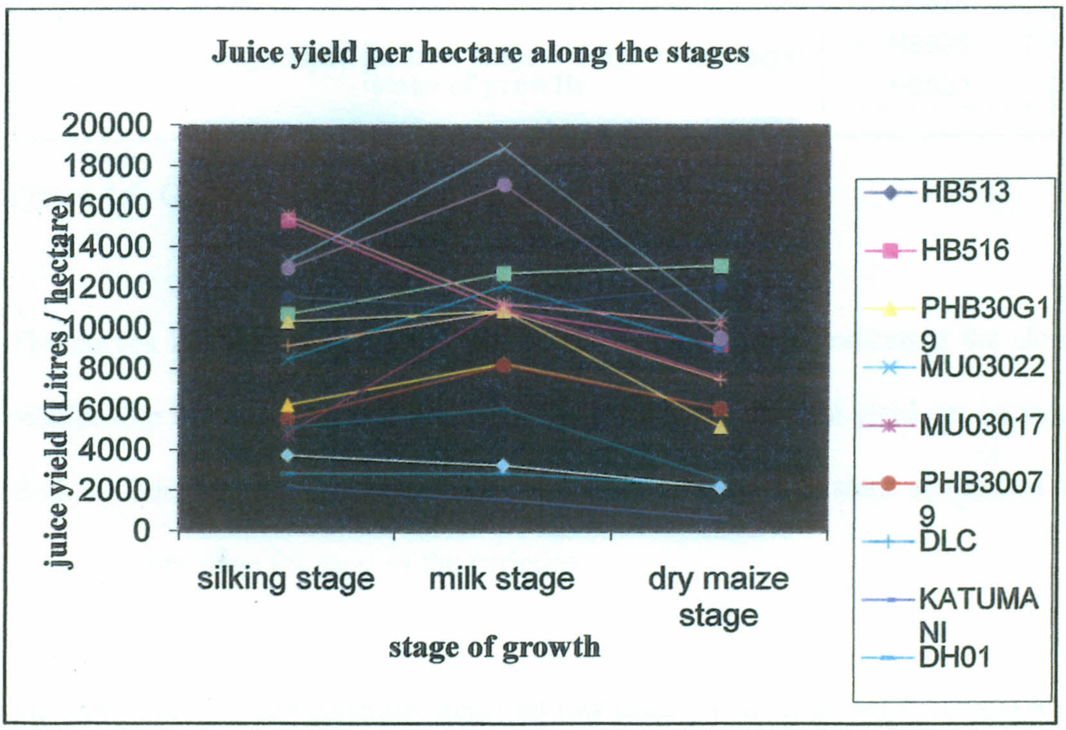


Figure 4.4: Graph of juice yield per hectare for maize stalk varieties

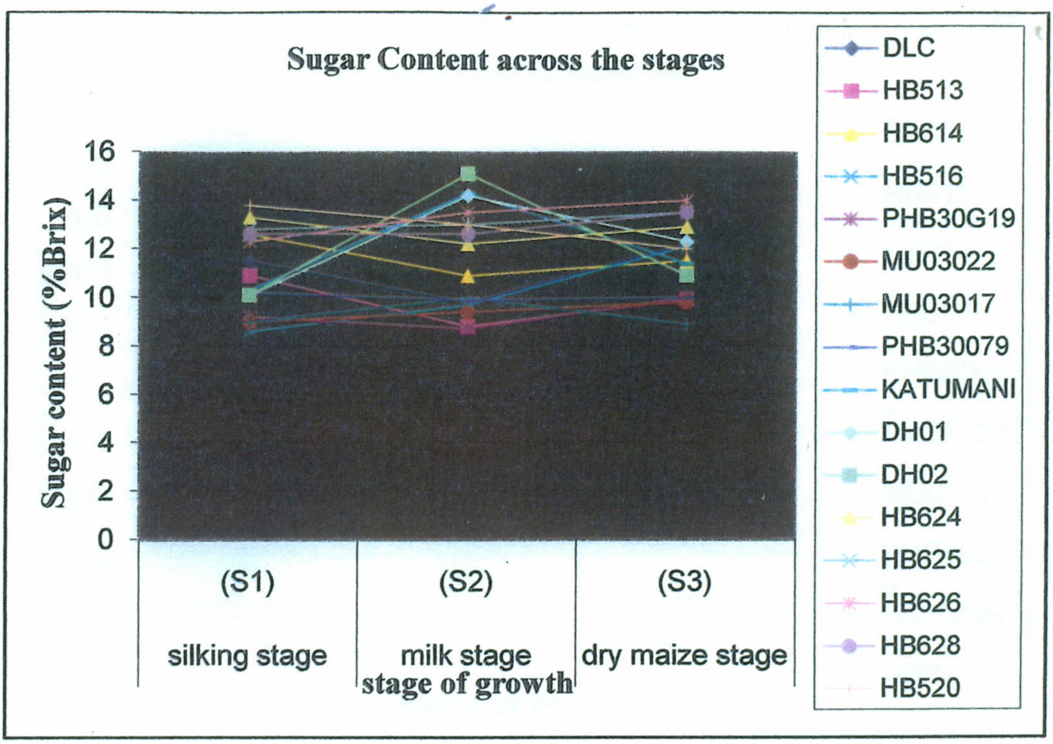


Figure 4.5: Graph of sugar content for maize stalk varieties

The curves in figure 4.4 and figure 4.6 had a similar trend indicating the close relationship between the juice yield per hectare and the ethanol yield per hectare. Both the juice yield and ethanol yield were highest at the milk stage and lowest at the dry maize stage for most of the varieties.

The dry land varieties generally depicted low juice yields, high sugar content and low ethanol yield per hectare. The hybrids for the high potential ecological zones had high juice yields and relatively high sugar content (range between 10 $^{0}$Brix and 13 $^{0}$Brix). This resulted in high ethanol yields.

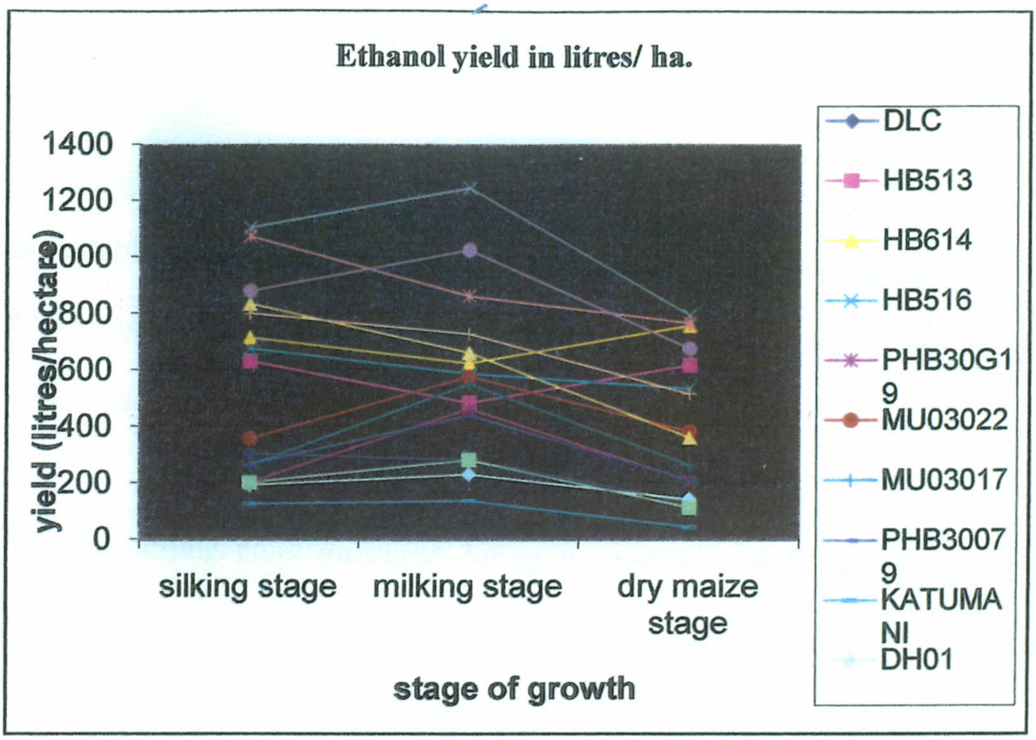


Figure 4.6: Graph of ethanol yield per hectare for maize stalk varieties

The medium potential varieties had low sugar levels (range between 8 $^{0}$Brix and 12 $^{0}$Brix) compared to the high potential varieties and the dry land varieties whose sugar levels ranged between 10 $^{0}$Brix and 15 $^{0}$Brix. However, their juice yield was between the values obtained from the dry land and the high potential varieties and so was their ethanol yields, agreeing with the trend of high juice yield leading to high ethanol yield.

The results gave an indication that the hybrids are better producers of ethanol. This compares to a related study by Reddy *et al.* (2007), which indicates that hybrid sorghum varieties have better ethanol yields compared to the other varieties.

**4.5 Suitability of ethanol derived from maize stalk juice for cooking**

The averaged values for the parameters tested for both Kerosene and ethanol (93%) were as listed in Table 4.13

The local boiling point measured during the test was 94 $^{0}$C since Nairobi is 1500m above sea level. The ambient temperature ranged between 19$^{0}$C and 20$^{0}$C during the entire testing period. The weight of the dry empty stove was 894gm and that of the dry empty pot was 308 gm. A 1000 gms of water was used in all the tests.

The lower heating value (LHV) of the ethanol used was 25.75 MJ/Kg as obtained in a test for hydrous ethanol (95%) (HE Blends BV 2007, 2007; Wayman and Hinman, 2008). It was assumed the 93% alcohol used in this test had an equal LHV to the 95% ethanol. The LHV for kerosene used was 42.90 MJ/Kg (Abou-Arab et al., 2001; Bouchez et al., 2005). There was a significant difference between the two types of fuel since the t-calculated values were above the t-critical as indicated in Table 4.14. The same quantity of water (1000gm) was heated in both cases when using kerosene and ethanol as fuel. It took almost double the time (17.30minutes) for water heated using ethanol to come to boiling temperature compared to that heated using kerosene which took 9.41minutes, but much more water was vaporized when heating with ethanol as a result. More fuel was used in the case of ethanol.

**Table 4.13: Water boiling test for ethanol and kerosene fuels**

| Parameter | Kerosene Mean±SD | Ethanol Mean±SD |
|---|---|---|
| Ambient temperature, $^0$c (T) | 19.00±0.00 | 20.00±0.00 |
| Initial water temperature, $^0$c ($T_{ci}$) | 19.00±0.00 | 19.55±0.47 |
| Weight of water + weight of pot at start of exp. g ($P_{ci}$) | 1308.00±0.00 | 1308±0.00 |
| Starting time, minutes ($t_{ci}$) | 0±0.00 | 0±0.00 |
| Weight of fuel at start of exp. in g, ($f_{ci}$) | 432.00±17.57 | 320.67±34.70 |
| Time when water reached local boiling point, minutes ($t_{cf}$) | 9.41±0.03 | 17.30±0.21 |
| Weight of water + weight of pot at end of exp., g ($P_{cf}$) | 1305.67±17.15 | 1171.33±35.93 |
| Water temperature after test, $^0$c ($T_{cf}$) | 94.00±0.00 | 94.00±0.00 |
| Weight of fuel at end of exp. in g, ($f_{cf}$) | 411.67±17.15 | 277.33±35.93 |
| Weight of fuel consumed, g ($f_{cm}$) | 20.33±0.47 | 43.33±1.25 |

**Table 4.14: Calculated variables for the water boiling test**

| Variable | Kerosene mean±SD | Ethanol mean±SD | $t_{calculated}$ |
|---|---|---|---|
| Weight of fuel consumed, g ($f_{cm}$) | 20.33±0.58 | 43.33±1.53 | 24.40 |
| Water vaporized, g ($w_{cv}$) | 33.67±3.06 | 54.67±3.79 | 7.48 |
| Water remaining at the end of the test, g ($w_{cr}$) | 966.33±3.06 | 945.33±3.79 | 7.48 |
| Duration of phase in minutes ($\Delta t_c$) | 9.41±0.04 | 17.30±0.25 | 53.66 |
| Thermal efficiency, %($h_c$) | 44.72±0.58 | 38.23±0.97 | 9.99 |
| Burning rate, g of fuel/min ($r_{cb}$) | 2.16±0.07 | 2.51±0.05 | 7.12 |
| Specific fuel consumption, g/g of water ($SC_c$) | 0.02±0.00 | 0.05±0.01 | 8.00 |
| Fire power, Watts ($FP_c$) | 1545±40.30 | 1075±18.25 | 13.34 |

t-critical at 95% confidence limit and df = 4 is 0.963

The fire power for kerosene obtained was 1.55 kW compared to 1.08 kW for ethanol. This difference in the fire power was explained by the fact that Kerosene has a higher lower heating value of 42.90 MJ/Kg (Abou-Arab et al., 2001; Bouchez et al., 2005) compared to that of ethanol which is 25.75 MJ/Kg (HE Blends BV 2007, 2007; Wayman and Hinman, 2008). But the fire power for both fuels was within the range for power output of wick stoves (0.8 - 2.2 kW) as concluded in a study by Stumpf, (2000) on plant oil as cooking fuel for stoves in the tropical and sub-tropical Africa. Stumpf also gave the range of efficiency as 38 - 47%, and the efficiency obtained in this study, 44.7% and 38.2% for kerosene and ethanol, respectively was within this range. Normally for stoves, the higher the thermal efficiency, the lower the specific fuel consumption as indicated in research by Robinson (2006). The study results agreed to this as kerosene gave a higher thermal efficiency and a corresponding lower Specific fuel consumption (0.02 g/g of water) compared to ethanol with a Specific fuel consumption of 0.05 g/g of water.

### 4.6 Determination ethanol production cost, the selling price and comparison with prevailing price for gasoline and kerosene.

#### 4.6.1 Introduction

The purpose for carrying out the product costing was to determine the selling price of ethanol as a fuel and compare it with the price of other fuels currently in use and establish whether it would be viable to use ethanol as a fuel.

This section presents results on the total production cost of ethanol, the estimated sale price of 10% ethanol and 90% gasoline blend and the comparison of this sale price with the prevailing market price of gasoline and kerosene. Detailed calculations are as given in Appendix H.

The economic analysis was based on the highest ethanol yielding variety on average and this was variety HB625. The analysis was done for the silking stage, the milk stage and the dry maize stage. The basis of the economic analysis was a litre of fuel (pure ethanol, pure gasoline, kerosene and 10% ethanol 90% gasoline blend). The main costs considered were the total production cost, estimated selling price of ethanol, the prevailing market price of gasoline and kerosene and the estimated selling price of the 10% ethanol and 90% gasoline blend. All the costs were based on 1litre of the fuel.

### 4.6.2 Ethanol production cost

The cost of processing the maize stalk juice into ethanol through fermentation and distillation was adopted from the Agro-Chemicals and Food Industries Ltd as given in Table 2.3. for the year 2009, since molasses compares with the maize stalk juice. The cost of molasses was subtracted and substituted with the cost of maize stalk juice.

The production cost of ethanol (from molasses) as adopted from ACFC is KSh. 52.47 (Table 3) minus the cost of molasses, KSh.13.04 to give the cost of production excluding the feedstock cost, as KSh.39.43. The cost of the feedstock was taken as the cost of the maize stalk juice.

#### 4.6.2.1 Cost of maize stalk juice

The cost of the maize stalk juice was taken as the cost of buying the maize stalks and the cost of crushing the stalks to get the juice.

#### 4.6.2.1a Cost of buying maize stalks

The assumption made here is that the maize stalks will be obtained from the conventional maize growing areas in the country. In Kenya, maize is grown for the grain which is a staple food. The maize stalks which are a by-product of maize farming are mainly used for feeding animals after the maize grain has been separated for mainly human consumption. The cost of the maize stalk when used to feed animals was therefore taken as the opportunity cost for the maize stalks if it were used to make ethanol and this cost was taken as the feedstock cost. The cost was taken as the mean of cost of maize stalks, collected from different farmers as in the Table 4.15. (Data collected in March 2010).

The Maize variety selected for economic analysis was HB625 with an ethanol yield 917.5 litre/hectare at the silking stage, 1445.5 litres/hectare at the milk stage and 825.04 litres/hectare at the dry maize stage (Table 4.12).

**Table 4.15: Cost of buying maize stalks**

| Name of farmer | Address of farmer | Cost of maize stalks per acre (KSh.) |
|---|---|---|
| Paul Kiriu | Mai-Mahiu, Naivasha | 7,000 |
| Benard Gitau | Sabasaba, Murang'a | 6,000 |
| Joseph Ndirangu | Ihururu, Nyeri | 10,000 |
| John Kahura | Nakuru | 2,000 |
| James Gitau | Nairobi | 8,000 |
| David Njaraganu | Kikuyu | 8,000 |
| Alice Wanjiru | Kikuyu | 7,000 |
| Samuel Njoroge | Kikuyu | 10,000 |
| Joseph Nganga | Kikuyu | 8,000 |
| **Average cost of maize stalks per acre** | | **7333.33** |

(Data obtained from questionnaires – Appendix J)

Calculated cost of maize stalks per litre of ethanol was per growth stage sampled

Silking stage = KSh.19.98

Milk stage = KSh.12.68

Dry maize stage = KSh. 22.22

**4.6.2.1b The cost of crushing the stalks per litre of juice obtained**

For HB 625, the average stalk weight in silking stage was 0.41kg/stalk, at the milk stage 0.54 kg/stalk and 0.37 kg/ stalk at the dry maize stage (Table 4).

The number of stalks per hectare was 106,640

Total weight of the stalks per hectare at the silking stage;

= 43,722.4Kg

= 43.72 tons

And the power required to crush this;

= 472.18kW = 0.51 kW per litre of ethanol produced

Total weight of the stalks per hectare at the milk stage;

= 57,585.6 Kg

= 57.59 tons

And the power required to crush this;

= 622.0 kW = 0.43 kW per litre of ethanol produced

Total weight of the stalks per hectare at the dry maize stage;

= 39,456.8 Kg

= 39.46 tons

And the power required to crush this;

= 426.17 kW= 0.52 kW per litre of ethanol produced

And the cost of crushing the stalks to give 1 litre ethanol at the silking stage was KSh. 6.12, KSh.5.16 at the milk stage and KSh.6.24 at the dry maize stage (assuming 1hr duration for crushing one ton of maize stalks).

#### 4.6.2.2 Total production cost of ethanol from maize stalk juice

Total cost of processing ethanol from maize stalks was;

= purchase cost of the maize stalks / hectare + cost of crushing maize stalks per hectare + cost of processing ethanol from maize stalk juice

At the silking stage the cost = KSh.65.53

At the milk stage the cost = KSh.57.27

At the dry maize stage the cost = KSh.67.89

### 4.6.3 Estimated sale price per litre of the ethanol

The projected sale price per litre of ethanol is 120% of the product cost of production (Peters and Timmerhaus, 1980), hence the projected sale price at each stage was as follows;

Silking stage = KSh.78.64

Milk stage = KSh.68.72

Dry maize stage = KSh. 81.47

### 4.6.4 Estimated sale price of the 10% ethanol 90% gasoline blend (E10) and kerosene fuel

The current retail price for gasoline in Nairobi area was as tabulated in Table 4.16.

The current average retail price of unleaded petrol (gasoline) = KSh.86.96 and for kerosene = KSh.63.45

**Table 4.16: Pump price for gasoline and kerosene in Nairobi**

| Petrol station | Location | Cost of unleaded petrol (KSh.) | Cost of kerosene (KSh.) |
|---|---|---|---|
| National oil | Outer-ring road | 84.30 | 62.00 |
| Total Kenya | Outer-ring road | 83.70 | 61.50 |
| Kobil | Airport North road | 83.60 | 61.90 |
| Oil-Libya | Mombasa road | 88.90 | 64.50 |
| Kenol | Mombasa road | 88.90 | 64.00 |
| Total Kenya | Mombasa road | 88.70 | 64.90 |
| Caltex | Mombasa road | 88.70 | 64.90 |
| Shell BP | Mombasa road | 88.90 | 63.90 |
| **Average price** | | **86.96** | **63.45** |

(As per survey done on March 24, 2010)

Gasoline proportion cost in the E10 blend = KSh. 78.26, and this was constant for all the stages.

At the silking stage the ethanol proportion cost in the E10 blend was;

= KSh.7.86

Therefore the estimated cost of 1litre of the blend was;

= cost of the ethanol proportion and the cost of the gasoline proportion

= KSh.86.12

At the milk stage the ethanol proportion cost in the E10 blend was;

= KSh.6.87

Therefore the estimated cost of 1litre of the blend was;

= cost of the ethanol proportion and the cost of the gasoline proportion

= KSh.85.13

At the dry maize stage the ethanol proportion cost of the E10 blend was;

= 8.15

Therefore the estimated cost of 1litre of the blend was;

= cost of the ethanol proportion and the cost of the gasoline proportion

= KSh.86.41

**4.6.5 Summary of the economic analysis**

The maize variety HB625 was chosen for the analysis due to its high ethanol yield compared to the other varieties studied. The costs analysed for each growth stage sampled was as in the Table 4.17.

The cost of ethanol production from maize stalk juice (KSh.65.53 at silking stage, KSh.57.27 at the milk stage and KSh. 67.89 at the dry maize stage) obtained in this study compares to the cost of ethanol production from wheat and sugar beet in the European Union at 0.59 €/l (about KSh.59) and 0.60 €/l (about KSh.60) respectively according to the GAIN report (2006).

**Table 4.17: Summary of economic analysis**

| Cost item | Cost (KSh.) (Silking stage) | Cost (KSh.) (Milk stage) | Cost (KSh.) (Dry maize stage) |
|---|---|---|---|
| Maize stalks (feedstock) | 19.98 | 12.68 | 22.22 |
| Crushing of the stalks | 6.12 | 5.16 | 6.24 |
| Processing of maize stalk juice into ethanol | 39.43 | 39.43 | 39.43 |
| Total cost of producing ethanol from maize stalks | 65.53 | 57.27 | 67.89 |
| **Sales** | | | |
| Projected sale price of pure ethanol | 78.64 | 68.72 | 81.47 |
| Retail price of kerosene | 63.45 | 63.45 | 63.45 |
| Retail price of pure gasoline | 86.96 | 86.96 | 86.96 |
| Estimated retail price of 10% ethanol 90% gasoline blend (E10) | 86.12 | 85.13 | 86.41 |
| Difference in cost of pure ethanol and kerosene ( kerosene price - ethanol price) | *-15.19 | *-5.27 | *-18.02 |
| Difference in cost of E10 and pure gasoline (gasoline price – E10 blend) | 0.84 | 1.83 | 0.55 |

*The negative sign indicates that the price of kerosene is lower than that of the ethanol.

The cost of E10 was slightly lower compared to the pure gasoline as at the time the study was conducted. The highest difference in price was obtained at the green maize stage with a difference of KSh.1.83 per liter. This price was determined by the feedstock used. Being an agricultural by-product, the price of maize stalk was low and its processing was not as energy intensive as starches or cellulosic materials (Janick and Whipkey, 2002), hence the cost of production compares to that of molasses.

For cooking purposes, pure ethanol was tested in a stove and therefore the cost comparison was between the projected sale price for the pure ethanol and the pump price for kerosene. The current average retail price for kerosene was KSh.63.45, much lower than the estimated sale price for ethanol in all the three stages, KSh.78.64 for the silking stage, KSh.68.72 for the milk stage and KSh.81.47 for the dry maize stage.

But the cost of ethanol from maize stalk juice could come down if more effort is put in improving efficiencies in the production process and the agricultural productivity. This would improve the yield and consequently the cost. This was the case of ethanol from sugarcane whose yield was improved from 2000 l/ha in 1975 to about 7000 l/ha in 2009 through research into improved production processes and improved productivity of the cane in terms of sugar content and juice yield. This has brought down the cost of ethanol from sugarcane to 0.15 €/liter (KSh.16.8 per liter) (Goldemberg, 2009), the lowest among all feedstocks.

# CHAPTER FIVE

## CONCLUSIONS AND RECOMMENDATIONS

The maize varieties were grown in the natural environment under typical field conditions as grown by farmers and were not given any special treatment. In doing this, it ensured that the data obtained can be used to estimate expected yields if farmers were contracted to grow maize stalks for ethanol production. The maize matured within the expected maturity periods of 3 months for the dry area varieties and 5 and 6 months for the hybrids as shown in Table 2.2. The plant population obtained for a hectare was 106640 stalks for high potential area varieties and 73926 stalks for low potential area varieties.

What was observed was that during the silking (stage 1) and milk stage (stage 2) sampling, the stalks were green in colour and very succulent. But at the dry maize stage (stage 3), the maize stalks had lost much of the green colour and had started turning brown and were less succulent.

The dry land composites (Katumani, DLC, DH01 and DH02) generally had short stalks. These stalks were drier at the dry stage with very little juice. The 600 series Hybrids (614, 624-628) had tall stalks which remained fairly succulent even at the dry maize stage.

The maize stalks contain juice which is sufficient to allow mechanical squeezing. The hybrid maize stalks contain juice even when the maize dries up and is ready for harvesting. The hybrids especially the 600 series give large amounts of juice up to above 18,000 liters/hectare. The lowest juice yield obtained was 616 litres/hectare for Katumani at the dry stage. The varieties with high juice yields are varieties with thick succulent stalks and high values of stalk weight. High juice yield per hectare for the hybrids is also due to the higher plant population compared to the dry land varieties.

The maize stalk juice contains fermentable sugars mainly glucose, fructose and sucrose. The range for the sugars in $^0$Brix was 8-15 for all the varieties at all the stages sampled. Dry land varieties have high $^0$Brix values compared to the hybrids. This translates to high ethanol yield in % (v/v) for these varieties though the ethanol yield per hectare still remains lower than for the hybrids due to the lower juice yield. The trend for transformation of specific sugars in the maize stalk juice is a decrease of the glucose and fructose levels and an increase of the sucrose levels as the plant matures.

Upon simple fermentation of the juice using baker's yeast, ethanol was obtained with the yield ranging between 42.12 litres/hectare and 1445.50 litres per hectare per planting. Since some regions do planting twice in a year in Kenya, this yield doubles for a given year. This yield is much lower compared to crops like sugar cane with a yield of 6192 litres/hectare. However this high yield for sugarcane has been achieved over years of research and this can also be done for maize stalks (Rahmani and Hodges, 2008). Plant breeders can boost the sugar levels and juice content of the maize stalks through research.

For all the varieties, the higher the stalk weight, the higher the juice yield per hectare and the higher the ethanol yield per hectare. Hybrids have high stalk weights ranging from 0.40±0.02 kg per stalk to 0.54±0.04kg per stalk and high plant population of 106640 stalks per hectare resulting to high juice yield per hectare and high ethanol yields per hectare hence making them the most suitable for ethanol production. Their maturity period is 6 months and in Kenya they can be cultivated biannually hence doubling their ethanol yields per year. For most of the hybrids, the yield of ethanol in the milk and dry stages do not give a significant difference and the yields are also high in these two stages hence this study recommends production of ethanol from these maize stalks at these two stages. At these two stages, the maize grain is also obtained either as green maize or dry maize thus ensuring food availability as well as ethanol production.

Among the dry land composites, the variety DLC gave the highest juice and ethanol yields per hectare and would be the best variety to grow for ethanol production in the dry ecological zones. For the medium potential ecological zone, the best ethanol yielding variety from those studied were the 500 hybrid series

(HB513, HB520 and HB516), which had similar yields. Variety HB625 was the highest ethanol yielding variety.

The ethanol power output and thermal efficiency when burnt in a stove was within expected range and this qualifies ethanol as a possible cooking fuel. However, for cooking purposes, the price of ethanol was much higher (as high as KSh.18 for ethanol made at the dry maize stage) than the current prices of kerosene. Irrespective of the environmental benefit, most consumers may consider it expensive and opt for the cheaper kerosene. There is need of optimizing the whole process of ethanol making from the maize stalk juice in order to make it cheaper.

The price per litre obtained for 10% ethanol- 90% gasoline blend falls within the current retail price for pure gasoline fuel. This makes it possible to substitute the pure gasoline with the blend without much price changes hence makes it easily acceptable to the consumer. This comes together with the gain of a cleaner environmental friendly fuel.

The results obtained in this study gives a basis for further research aiming towards making maize stalks a sustainable feedstock for ethanol production in Kenya. Further research is recommended in boosting the sugar content and juice content and also in establishing the effect of different factors like season, soil type and ecological zone, on the juice and sugar content of the maize stalks. Optimization of the process especially for juice extraction needs to be optimized to raise the juice yield. A detailed economic study is also recommended so as to come up with the actual benefits of using maize stalks as a resource for ethanol production.

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# APPENDICES

## APPENDIX A: JUICE YIELD AND SUGAR CONTENT RAW DATA FOR ALL MAIZE VARIETIES STUDIED

### Table A1: DLC juice yield and sugar content

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Sample Juice yield (ml) | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 74 | 113 | 102 | - | - | - | 96.3 | 0.71 | 200 | 10.9 | 10.8 | 9.8 | 10.9 |
| **S1.2** | 98 | 99 | 108 | - | - | - | 101.7 | 0.76 | 270 | 12.0 | 12.2 | 12.0 | 12.1 |
| **S1.3** | 81 | 95 | 89 | - | - | - | 88.3 | 0.62 | 150 | 11.7 | 11.3 | 11.6 | 11.5 |
| AVERAGES | | | | | | | 95.4 | 0.69 | 206.6 | | | | 11.5 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 79 | 136 | 115 | - | - | - | 110.0 | 0.87 | 265 | 10.5 | 10.7 | 10.6 | 10.6 |
| **S2.2** | 72 | 100 | 108 | - | - | - | 93.3 | 0.74 | 205 | 9.2 | 9.2 | 9.1 | 9.2 |
| **S2.3** | 122 | 123 | 112 | - | - | - | 119.0 | 0.96 | 265 | 9.5 | 9.8 | 9.7 | 9.7 |
| AVERAGES | | | | | | | 107.4 | 0.86 | 245.0 | | | | 9.8 |
| **Dry maize stage(S3)** | | | | | | | | | | | | | |
| **S3.1** | 73 | 95 | 54 | 104 | 66 | - | 78.4 | 1.05 | 150 | 12.3 | 12.5 | 12.2 | 12.4 |
| **S3.2** | 101 | 101 | 120 | 83 | 101 | - | 101.2 | 1.00 | 225 | 11.8 | 11.7 | 11.6 | 11.7 |
| **S3.3** | 70 | 94 | 88 | 95 | 84 | - | 86.2 | 0.84 | 140 | 12.7 | 12.3 | 12.2 | 12.4 |
| AVERAGES | | | | | | | 88.6 | 0.96 | 171.7 | | | | 12.2 |

**Table A2: HB 513 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield (ml) | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 152 | 160 | 180 | 123 | 117 | 138 | 145.0 | 2.26 | 760 | 11.1 | 11.1 | 11.2 | 11.1 |
| **S1.2** | 113 | 104 | 114 | 136 | 120 | 155 | 123.7 | 2.24 | 750 | 10.8 | 10.5 | 10.7 | 10.7 |
| **S1.3** | 129 | 114 | 118 | 120 | 146 | 93 | 118.5 | 1.70 | 430 | 10.9 | 10.8 | 10.9 | 10.9 |
| AVERAGES | | | | | | | 129.1 | 2.07 | 647.0 | | | | 10.9 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 152 | 120 | 180 | 150 | 113 | 178 | 148.8 | 2.02 | 570 | 8.4 | 8.5 | 8.3 | 8.4 |
| **S2.2** | 180 | 176 | 124 | 153 | 160 | 120 | 152.1 | 2.23 | 730 | 8.8 | 9.0 | 9.0 | 8.9 |
| **S2.3** | 114 | 139 | 133 | 164 | 113 | 136 | 133.2 | 2.09 | 550 | 9.3 | 9.3 | 8.8 | 9.1 |
| AVERAGES | | | | | | | 144.7 | 2.11 | 616.7 | | | | 8.8 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 134 | 136 | 141 | 149 | - | - | 140 | 1.42 | 430 | 11.6 | 11.4 | 11.6 | 11.5 |
| **S3.2** | 112 | 156 | 132 | 136 | - | - | 134 | 1.35 | 490 | 8.9 | 8.7 | 8.8 | 8.8 |
| **S3.3** | 155 | 136 | 127 | 114 | - | - | 133 | 1.33 | 440 | 9.4 | 9.4 | 9.4 | 9.4 |
| AVERAGES | | | | | | | 135.7 | 1.37 | 453.3 | | | | 9.9 |

**Table A3: HB 614 Juice yield and sugar content**

| sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield (ml) | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage(S1)** | | | | | | | | | | | | | |
| **S1.1** | 180 | 130 | 130 | 179 | 173 | 182 | 162 | 1.84 | 520 | 13.2 | 13.3 | 13.1 | 13.2 |
| **S1.2** | 183 | 182 | 145 | 162 | 157 | 125 | 159 | 1.92 | 610 | 11.8 | 12.0 | 12.0 | 12.0 |
| **S1.3** | 167 | 194 | 200 | 154 | 166 | 168 | 175 | 2.16 | 670 | 12.6 | 12.6 | 12.6 | 12.6 |
| AVERAGES | | | | | | | 165.3 | 1.97 | 600 | | | | 12.6 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 184 | 196 | 192 | 174 | 153 | - | 180 | 2.01 | 700 | 11.0 | 10.7 | 10.6 | 10.8 |
| **S2.2** | 146 | 170 | 170 | 138 | 144 | - | 154 | 1.88 | 660 | 11.0 | 10.8 | 10.9 | 10.9 |
| **S2.3** | 170 | 158 | 180 | 183 | 176 | - | 173 | 2.09 | 780 | 11.2 | 11.0 | 11.1 | 11.1 |
| AVERAGES | | | | | | | 169 | 1.99 | 713.3 | | | | 10.9 |
| **Dry maize (S3)** | | | | | | | | | | | | | |
| **S3.1** | 140 | 171 | 166 | - | - | - | 159 | 1.66 | 530 | 12.2 | 12.1 | 12.2 | 12.2 |
| **S3.2** | 159 | 187 | 138 | - | - | - | 161 | 1.63 | 450 | 12.1 | 12.2 | 12.2 | 12.1 |
| **S3.3** | 159 | 172 | 188 | - | - | - | 173 | 1.58 | 490 | 10.4 | 10.1 | 10.1 | 10.2 |
| AVERAGES | | | | | | | 164.3 | 1.62 | 490.0 | | | | 11.5 |

**Table A4: HB 516 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield (ml) | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 130 | 151 | 149 | 118 | - | - | 137 | 1.37 | 520 | 8.8 | 8.8 | 8.9 | 8.8 |
| **S1.2** | 160 | 151 | 146 | 169 | - | - | 157 | 1.51 | 620 | 8.9 | 8.8 | 8.7 | 8.8 |
| **S1.3** | 130 | 141 | 112 | 110 | - | - | 123 | 1.27 | 580 | 8.2 | 8.2 | 8.4 | 8.3 |
| AVERAGES | | | | | | | 139 | 1.38 | 573.3 | | | | 8.6 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 150 | 124 | 128 | 126 | - | - | 133 | 1.01 | 440 | 9.6 | 9.8 | 9.8 | 9.7 |
| **S2.2** | 123 | 115 | 127 | 127 | - | - | 123 | 1.19 | 400 | 10.0 | 9.5 | 9.6 | 9.7 |
| **S2.3** | 130 | 124 | 125 | 124 | - | - | 126 | 0.95 | 380 | 9.7 | 9.8 | 9.8 | 9.8 |
| AVERAGES | | | | | | | 127.3 | 1.05 | 406.7 | | | | 9.7 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 141 | 142 | 134 | 136 | - | - | 138 | 1.21 | 250 | 12.4 | 12.5 | 12.5 | 12.5 |
| **S3.2** | 129 | 130 | 125 | 142 | - | - | 132 | 1.25 | 340 | 11.2 | 11.2 | 11.0 | 11.1 |
| **S3.3** | 127 | 160 | 155 | 164 | - | - | 152 | 1.53 | 440 | 12.6 | 12.7 | 12.6 | 12.6 |
| AVERAGES | | | | | | | 140.7 | 1.33 | 343.3 | | | | 12.1 |

**Table A5: PHB 30079 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 99 | 91 | 101 | 101 | - | - | 98 | 0.65 | 200 | 11.1 | 11.1 | 11.1 | 11.1 |
| **S1.2** | 120 | 146 | 113 | 117 | - | - | 124 | 0.88 | 240 | 9.9 | 10.0 | 9.9 | 9.9 |
| **S1.3** | 126 | 80 | 96 | 102 | - | - | 101 | 0.61 | 180 | 9.7 | 9.7 | 9.9 | 9.7 |
| AVERAGES | | | | | | | 107.7 | 0.71 | 206.7 | | | | 10.2 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 129 | 127 | 139 | 78 | - | - | 118 | 0.99 | 340 | 9.8 | 9.3 | 9.5 | 9.5 |
| **S2.2** | 139 | 139 | 98 | 111 | - | - | 122 | 0.88 | 320 | 10.5 | 10.4 | 10.4 | 10.4 |
| **S2.3** | 135 | 128 | 137 | 107 | - | - | 127 | 0.78 | 260 | 10.3 | 9.9 | 10.0 | 10.0 |
| AVERAGES | | | | | | | 122.3 | 0.88 | 306.7 | | | | 9.9 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 92 | 110 | 116 | 123 | - | - | 110 | 0.89 | 210 | 10.1 | 10.0 | 10.1 | 10.1 |
| **S3.2** | 113 | 111 | 98 | 86 | - | - | 102 | 1.02 | 220 | 9.9 | 9.9 | 10.1 | 10.0 |
| **S3.3** | 128 | 116 | 118 | 93 | - | - | 114 | 1.10 | 250 | 9.9 | 10.0 | 10.0 | 10.0 |
| AVERAGES | | | | | | | 108.7 | 1.00 | 226.7 | | | | 10.0 |

**Table A6: PHB 30G19 Juice yield and Sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 150 | 133 | 159 | 94 | - | - | 134 | 0.76 | 160 | 9.9 | 10.0 | 10.0 | 9.9 |
| **S1.2** | 124 | 142 | 166 | 102 | - | - | 134 | 0.87 | 310 | 9.0 | 9.0 | 9.0 | 9.0 |
| **S1.3** | 109 | 106 | 147 | 100 | - | - | 116 | 0.70 | 230 | 8.8 | 8.7 | 8.7 | 8.8 |
| AVERAGES | | | | | | | 128 | 0.78 | 233.3 | | | | 9.2 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 129 | 147 | 129 | 130 | - | - | 134 | 0.91 | 320 | 8.8 | 8.7 | 8.8 | 8.8 |
| **S2.2** | 157 | 140 | 163 | 135 | - | - | 149 | 0.84 | 280 | 8.3 | 8.5 | 8.6 | 8.5 |
| **S2.3** | 90 | 127 | 162 | 110 | - | - | 122 | 0.95 | 330 | 9.0 | 8.9 | 9.0 | 8.9 |
| AVERAGES | | | | | | | 135 | 0.90 | 310 | | | | 8.7 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 131 | 135 | 110 | 126 | - | - | 126 | 0.93 | 200 | 9.8 | 9.5 | 9.6 | 9.6 |
| **S3.2** | 97 | 104 | 89 | 98 | - | - | 97 | 0.91 | 270 | 10.7 | 10.4 | 10.3 | 10.5 |
| **S3.3** | 119 | 115 | 96 | 117 | - | - | 112 | 0.84 | 210 | 10.0 | 9.9 | 10.0 | 10.0 |
| AVERAGES | | | | | | | 111.7 | 0.89 | 226.7 | | | | 10.0 |

**Table A7: MU 022 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 111 | 163 | 134 | 124 | - | - | 133 | 0.74 | 270 | 9.7 | 9.4 | 9.4 | 9.5 |
| **S1.2** | 129 | 98 | 79 | 130 | - | - | 109 | 1.14 | 430 | 8.9 | 9.0 | 8.9 | 8.9 |
| **S1.3** | 100 | 138 | 136 | 80 | - | - | 114 | 0.70 | 250 | 8.8 | 8.6 | 8.6 | 8.7 |
| AVERAGES | | | | | | | 118.7 | 0.86 | 316.7 | | | | 9.0 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 126 | 120 | 121 | 110 | - | - | 119 | 0.92 | 400 | 9.7 | 9.5 | 9.6 | 9.6 |
| **S2.2** | 125 | 149 | 142 | 134 | - | - | 138 | 0.92 | 350 | 9.5 | 9.5 | 9.6 | 9.5 |
| **S2.3** | 147 | 142 | 130 | 130 | - | - | 137 | 1.26 | 610 | 8.9 | 9.0 | 9.0 | 9.0 |
| AVERAGES | | | | | | | 131.3 | 1.03 | 453.3 | | | | 9.4 |
| **Dry maize(S3)** | | | | | | | | | | | | | |
| **S3.1** | 121 | 130 | 156 | 129 | - | - | 134 | 1.60 | 450 | 8.6 | 8.6 | 8.6 | 8.6 |
| **S3.2** | 137 | 120 | 122 | 116 | - | - | 124 | 1.22 | 300 | 10.6 | 10.4 | 10.6 | 10.5 |
| **S3.3** | 124 | 115 | 114 | 119 | - | - | 118 | 1.12 | 260 | 10.4 | 10.3 | 10.4 | 10.4 |
| AVERAGES | | | | | | | 125.3 | 1.31 | 336.7 | | | | 9.8 |

**Table A8: MU 017 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage(S1)** | | | | | | | | | | | | | |
| **S1.1** | 93 | 92 | 127 | 130 | - | - | 111 | 0.62 | 170 | 8.7 | 8.6 | 8.7 | 8.7 |
| **S1.2** | 120 | 118 | 95 | 110 | - | - | 111 | 0.57 | 190 | 8.4 | 8.4 | 8.3 | 8.4 |
| **S1.3** | 127 | 140 | 76 | 102 | - | - | 111 | 0.55 | 180 | 9.8 | 9.8 | 9.9 | 9.8 |
| AVERAGES | | | | | | | 111 | 0.58 | 180 | | | | 9.0 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 126 | 130 | 139 | 134 | - | - | 132 | 1.32 | 520 | 10.1 | 10.3 | 10.1 | 10.1 |
| **S2.2** | 132 | 108 | 136 | 103 | - | - | 120 | 0.95 | 360 | 9.9 | 10.0 | 9.9 | 9.9 |
| **S2.3** | 128 | 124 | 126 | 131 | - | - | 127 | 0.96 | 360 | 9.9 | 9.8 | 9.9 | 9.9 |
| AVERAGES | | | | | | | 126.3 | 1.10 | 413.3 | | | | 10.0 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 136 | 129 | 121 | 108 | - | - | 124 | 1.12 | 280 | 9.5 | 9.8 | 9.6 | 9.6 |
| **S3.2** | 127 | 130 | 135 | 141 | - | - | 133 | 0.97 | 270 | 8.3 | 8.3 | 8.4 | 8.3 |
| **S3.3** | 109 | 144 | 143 | 132 | - | - | 132 | 1.23 | 300 | 8.6 | 8.7 | 8.7 | 8.7 |
| AVERAGES | | | | | | | 130 | 1.11 | 283.3 | | | | 8.9 |

**Table A9: KATUMANI Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage(S1)** | | | | | | | | | | | | | |
| **S1.1** | 90 | 84 | 81 | 92 | - | - | 86.8 | 0.43 | 130 | 9.9 | 10.0 | 10.3 | 10.1 |
| **S1.2** | 116 | 85 | 75 | 80 | - | - | 89.0 | 0.47 | 120 | 10.3 | 10.4 | 10.3 | 10.3 |
| **S1.3** | 102 | 91 | 94 | 82 | - | - | 92.3 | 0.47 | 100 | 9.9 | 10.0 | 10.0 | 10.0 |
| AVERAGES | | | | | | | 89.4 | 0.46 | 116.7 | | | | 10.1 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 67 | 85 | 94 | 120 | - | - | 91.5 | 0.30 | 90 | 14.3 | 14.2 | 14.3 | 14.3 |
| **S2.2** | 91 | 122 | 120 | 124 | - | - | 114.3 | 0.32 | 100 | 14.3 | 14.1 | 14.0 | 14.1 |
| **S2.3** | 128 | 109 | 67 | 99 | - | - | 100.8 | 0.28 | 55 | 14.2 | 14.2 | 14.2 | 14.2 |
| AVERAGES | | | | | | | 102.2 | 0.30 | 81.7 | | | | 14.2 |
| **Dry maize (S3)** | | | | | | | | | | | | | |
| **S3.1** | 80 | 75 | 102 | 86 | - | - | 85.8 | 0.17 | 25 | 11.4 | 11.5 | 11.5 | 11.5 |
| **S3.2** | 80 | 120 | 104 | 87 | - | - | 97.8 | 0.24 | 40 | 11.0 | 11.2 | 11.2 | 11.1 |
| **S3.3** | 101 | 93 | 92 | 61 | - | - | 86.8 | 0.22 | 35 | 11.2 | 11.4 | 11.4 | 11.4 |
| AVERAGES | | | | | | | 90.1 | 0.21 | 33.3 | | | | 11.3 |

**Table A10: DH01 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage(S1)** | | | | | | | | | | | | | |
| **S1.1** | 84 | 82 | 80 | 91 | - | - | 84.3 | 0.48 | 130 | 10.1 | 10.1 | 10.2 | 10.1 |
| **S1.2** | 80 | 95 | 80 | 86 | - | - | 85.3 | 0.48 | 145 | 10.0 | 10.1 | 10.1 | 10.1 |
| **S1.3** | 93 | 94 | 102 | 110 | - | - | 99.8 | 0.64 | 180 | 10.1 | 9.9 | 10.0 | 10.0 |
| AVERAGES | | | | | | | 89.8 | 0.53 | 151.7 | | | | 10.1 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 107 | 135 | 120 | 112 | - | - | 118.5 | 0.50 | 115 | 14.5 | 14.7 | 14.7 | 14.7 |
| **S2.2** | 129 | 103 | 129 | 134 | - | - | 123.8 | 0.69 | 165 | 13.4 | 13.6 | 13.4 | 13.4 |
| **S2.3** | 141 | 135 | 101 | 102 | - | - | 119.8 | 0.67 | 180 | 14.9 | 14.9 | 15.0 | 14.9 |
| AVERAGES | | | | | | | 120.7 | 0.62 | 153.3 | | | | 14.3 |
| **Dry maize stage(S3)** | | | | | | | | | | | | | |
| **S3.1** | 100 | 113 | 128 | 110 | - | - | 112.8 | 0.60 | 145 | 12.1 | 12.3 | 12.3 | 12.3 |
| **S3.2** | 110 | 115 | 120 | 125 | - | - | 117.5 | 0.46 | 110 | 12.3 | 12.2 | 12.3 | 12.3 |
| **S3.3** | 146 | 110 | 146 | 108 | - | - | 127.5 | 0.43 | 105 | 12.4 | 12.3 | 23.4 | 12.4 |
| AVERAGES | | | | | | | 119.3 | 0.50 | 120 | | | | 12.3 |

**Table A11: DH02 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 90 | 107 | 113 | 80 | - | - | 97.5 | 0.69 | 185 | 10.1 | 10.1 | 10.1 | 10.1 |
| **S1.2** | 102 | 117 | 100 | 95 | - | - | 103.5 | 0.62 | 170 | 10.0 | 10.1 | 10.1 | 10.1 |
| **S1.3** | 116 | 104 | 82 | 86 | - | - | 97.0 | 0.61 | 250 | 10.1 | 10.0 | 10.1 | 10.1 |
| AVERAGES | | | | | | | 99.3 | 0.64 | 201.7 | | | | 10.1 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 143 | 133 | 128 | 130 | - | - | 133.5 | 0.91 | 255 | 15.8 | 15.8 | 15.9 | 15.8 |
| **S2.2** | 110 | 129 | 130 | 154 | - | - | 130.8 | 0.77 | 150 | 15.5 | 15.3 | 15.4 | 15.4 |
| **S2.3** | 139 | 110 | 100 | 130 | - | - | 119.8 | 0.60 | 120 | 14.4 | 14.2 | 14.1 | 14.2 |
| AVERAGES | | | | | | | 128.0 | 0.76 | 175 | | | | 15.1 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 97 | 172 | 126 | 106 | - | - | 125.3 | 0.64 | 135 | 10.7 | 10.9 | 10.9 | 10.9 |
| **S3.2** | 130 | 144 | 109 | 116 | - | - | 124.8 | 0.59 | 110 | 10.9 | 10.9 | 10.8 | 10.9 |
| **S3.3** | 144 | 100 | 141 | 93 | - | - | 119.5 | 0.54 | 105 | 10.9 | 11.1 | 11.0 | 11.0 |
| AVERAGES | | | | | | | 123.2 | 0.59 | 111.7 | | | | 10.9 |

**Table A12: HB 624 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 160 | 148 | 138 | 141 | - | - | 146.8 | 1.41 | 470 | 12.8 | 12.9 | 12.9 | 12.9 |
| **S1.2** | 174 | 154 | 114 | 177 | - | - | 154.8 | 1.25 | 320 | 13.4 | 13.2 | 13.2 | 13.3 |
| **S1.3** | 126 | 170 | 159 | 163 | - | - | 117 | 1.29 | 370 | 13.6 | 13.5 | 13.3 | 13.5 |
| AVERAGES | | | | | | | 139.5 | 1.32 | 386.7 | | | | 13.2 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 238 | 136 | 218 | 164 | - | - | 189 | 1.72 | 440 | 11.9 | 11.9 | 11.9 | 11.9 |
| **S2.2** | 180 | 204 | 165 | 150 | - | - | 174.8 | 1.51 | 380 | 12.5 | 12.6 | 12.6 | 12.6 |
| **S2.3** | 148 | 153 | 162 | 169 | - | - | 158 | 1.40 | 360 | 12.0 | 12.1 | 12.1 | 12.1 |
| AVERAGES | | | | | | | 173.9 | 1.54 | 393.3 | | | | 12.2 |
| **Dry maize stage(S3)** | | | | | | | | | | | | | |
| **S3.1** | 147 | 146 | 140 | 140 | - | - | 134 | 1.28 | 330 | 12.9 | 12.9 | 12.6 | 12.9 |
| **S3.2** | 174 | 130 | 134 | 124 | - | - | 141 | 1.04 | 260 | 13.3 | 13.2 | 13.3 | 13.3 |
| **S3.3** | 131 | 84 | 130 | 108 | - | - | 113 | 0.75 | 110 | 14.0 | 14.0 | 14.0 | 14.0 |
| AVERAGES- | | | | | | | 129.3 | 1.02 | 233.3 | | | | 13.4 |

**Table A13: HB 625 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 159 | 163 | 160 | 107 | - | - | 147.3 | 1.50 | 440 | 12.5 | 12.5 | 12.4 | 12.5 |
| **S1.2** | 122 | 125 | 179 | 190 | - | - | 154.0 | 1.77 | 600 | 13.6 | 13.4 | 13.6 | 13.6 |
| **S1.3** | 116 | 169 | 127 | 154 | - | - | 141.5 | 1.66 | 455 | 12.8 | 12.9 | 12.9 | 12.9 |
| AVERAGES | | | | | | | 147.6 | 1.64 | 498.3 | | | | 13.0 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 151 | 206 | 164 | 210 | - | - | 182.8 | 2.03 | 670 | 13.1 | 13.0 | 13.1 | 13.1 |
| **S2.2** | 171 | 179 | 192 | 179 | - | - | 180.3 | 2.31 | 650 | 13.1 | 13.0 | 13.0 | 13.0 |
| **S2.3** | 182 | 168 | 165 | 163 | - | - | 169.5 | 2.11 | 800 | 12.6 | 13.0 | 12.8 | 12.8 |
| AVERAGES | | | | | | | 177.5 | 2.15 | 706.7 | | | | 13.0 |
| **Dry Maize stage(S3)** | | | | | | | | | | | | | |
| **S3.1** | 152 | 134 | 163 | 150 | - | - | 150 | 1.42 | 320 | 11.9 | 11.9 | 11.9 | 11.9 |
| **S3.2** | 172 | 136 | 117 | 163 | - | - | 147 | 1.74 | 500 | 12.7 | 12.7 | 12.8 | 12.7 |
| **S3.3** | 125 | 160 | 132 | 150 | - | - | 142 | 1.27 | 370 | 15.0 | 14.9 | 15.0 | 15.0 |
| AVERAGES | | | | | | | 146.3 | 1.48 | 396.7 | | | | 13.2 |

**Table A14: HB 626 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 180 | 164 | 165 | 176 | - | - | 171.3 | 2.18 | 625 | 12.6 | 12.6 | 12.6 | 12.6 |
| **S1.2** | 116 | 164 | 153 | 89 | - | - | 130.5 | 1.61 | 750 | 12.0 | 11.9 | 12.0 | 12.0 |
| **S1.3** | 107 | 137 | 116 | 127 | - | - | 121.8 | 1.19 | 375 | 11.9 | 11.9 | 11.9 | 11.9 |
| AVERAGES | | | | | | | 141.2 | 1.66 | 583.3 | | | | 12.2 |
| **Milk stage(S2)** | | | | | | | | | | | | | |
| **S2.1** | 180 | 192 | 146 | 131 | - | - | 162.3 | 1.74 | 390 | 14.1 | 14.0 | 14.1 | 14.1 |
| **S2.2** | 200 | 177 | 124 | 203 | - | - | 176 | 1.94 | 550 | 13.3 | 13.3 | 13.3 | 13.3 |
| **S2.3** | 162 | 151 | 105 | 160 | - | - | 192.7 | 1.42 | 320 | 13.2 | 13.2 | 13.1 | 13.2 |
| AVERAGES | | | | | | | 177 | 1.70 | 420 | | | | 13.5 |
| **Dry Maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 128 | 168 | 146 | 148 | - | - | 148 | 1.25 | 370 | 12.5 | 12.5 | 12.4 | 12.5 |
| **S3.2** | 123 | 122 | 134 | 185 | - | - | 141 | 1.51 | 360 | 13.6 | 13.6 | 13.7 | 13.6 |
| **S3.3** | 137 | 128 | 121 | 172 | - | - | 140 | 1.66 | 420 | 15.2 | 15.1 | 15.2 | 15.2 |
| AVERAGES | | | | | | | 143 | 1.47 | 383.3 | | | | 13.8 |

**Table A15: HB 628 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 136 | 138 | 133 | 206 | - | - | 153.3 | 2.00 | 700 | 12.2 | 12.2 | 12.1 | 12.2 |
| **S1.2** | 128 | 155 | 146 | 117 | - | - | 136.5 | 1.35 | 435 | 12.2 | 12.3 | 12.3 | 12.3 |
| **S1.3** | 110 | 112 | 133 | 165 | - | - | 130.0 | 1.02 | 320 | 13.3 | 13.4 | 13.5 | 13.4 |
| AVERAGES | | | | | | | 140.0 | 1.46 | 485 | | | | 12.6 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 160 | 181 | 156 | 176 | - | - | 168.3 | 2.16 | 560 | 12.9 | 12.8 | 12.9 | 12.9 |
| **S2.2** | 184 | 157 | 186 | 164 | - | - | 173.3 | 2.29 | 780 | 12.4 | 12.4 | 12.3 | 12.4 |
| **S2.3** | 164 | 155 | 186 | 173 | - | - | 169.5 | 1.86 | 580 | 12.4 | 12.4 | 12.4 | 12.4 |
| AVERAGES | | | | | | | 170.4 | 2.10 | 640 | | | | 12.6 |
| **Dry Maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 165 | 170 | 148 | 178 | - | - | 165 | 1.60 | 330 | 14.1 | 14.2 | 14.2 | 14.2 |
| **S3.2** | 124 | 174 | 101 | 103 | - | - | 126 | 1.23 | 320 | 14.4 | 14.3 | 14.2 | 14.3 |
| **S3.3** | 170 | 136 | 174 | 146 | - | - | 157 | 1.52 | 420 | 13.1 | 13.0 | 13.1 | 13.1 |
| AVERAGES | | | | | | | 149.3 | 1.45 | 356.7 | | | | 13.8 |

**Table A16: HB 520 Juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Juice yield | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage (S1)** | | | | | | | | | | | | | |
| **S1.1** | 141 | 160 | 162 | 148 | - | - | 152.8 | 1.03 | 260 | 14.1 | 14.2 | 14.2 | 14.2 |
| **S1.2** | 155 | 158 | 163 | 161 | - | - | 159.3 | 1.35 | 370 | 13.5 | 13.3 | 13.5 | 13.4 |
| **S1.3** | 167 | 150 | 163 | 135 | - | - | 153.8 | 0.95 | 395 | 13.5 | 13.6 | 13.6 | 13.6 |
| AVERAGES | | | | | | | 155.3 | 1.11 | 341.7 | | | | 13.7 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 128 | 127 | 152 | 121 | - | - | 132.0 | 1.59 | 470 | 12.9 | 13.2 | 13.1 | 13.1 |
| **S2.2** | 123 | 120 | 113 | 117 | - | - | 118.3 | 1.17 | 350 | 13.0 | 13.1 | 13.1 | 13.1 |
| **S2.3** | 107 | 122 | 135 | 160 | - | - | 131.0 | 1.24 | 400 | 12.8 | 12.8 | 12.8 | 12.8 |
| AVERAGES | | | | | | | 127.1 | 1.33 | 406.7 | | | | 13.0 |
| **Dry maize stage(S3)** | | | | | | | | | | | | | |
| **S3.1** | 144 | 111 | 140 | 142 | - | - | 134 | 1.08 | 210 | 11.9 | 12.0 | 12.0 | 12.0 |
| **S3.2** | 102 | 158 | 158 | 144 | - | - | 141 | 1.36 | 280 | 11.8 | 11.5 | 11.5 | 11.6 |
| **S3.3** | 143 | 173 | 115 | 114 | - | - | 136 | 1.21 | 350 | 12.5 | 12.5 | 12.4 | 12.5 |
| AVERAGES- | | | | | | | 136.3 | 1.22 | 280 | | | | 12.0 |

## APPENDIX B: RAW DATA ON ETHANOL YIELD FOR ALL THE VARIETIES

**Table B1: DLC fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 11.7 | 4.8 | 4.9 | 5.8 |
| **S1.2** | 11.8 | 4.6 | 4.9 | 6.0 |
| **S1.3** | 11.8 | 4.6 | 4.8 | 5.9 |
| **AVERAGE** | | 4.7 | 4.9 | 5.9 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 10.0 | 3.7 | 3.9 | 4.4 |
| **S2.2** | 9.9 | 3.8 | 3.7 | 4.8 |
| **S2.3** | 9.9 | 3.9 | 3.7 | 4.6 |
| **AVERAGE** | | 3.8 | 3.7 | 4.6 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 12.4 | 5.4 | 5.4 | 5.0 |
| **S3.2** | 12.3 | 5.3 | 5.3 | 5.2 |
| **S3.3** | 12.4 | 5.3 | 5.3 | 5.1 |
| **AVERAGE** | 12.4 | 5.3 | 5.3 | 5.1 |

- Vol.of juice fermented:S1 = 150ml; S2 = 200ml; S3 = 230ml
- pH of juice: S1 = 4.6; S2 = 5.3; S4 = 5.3

**Table B2: HB 513 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1** | | | | |
| **S1.1** | 11.1 | 4.3 | 4.2 | 5.58 |
| **S1.2** | 10.7 | 4.5 | 4.3 | 5.37 |
| **S1.3** | 10.9 | 4.4 | 4.3 | 5.48 |
| **AVERAGE** | 10.9 | 4.4 | 4.3 | 5.48 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 8.6 | 3.2 | 3.2 | 4.65 |
| **S2.2** | 8.5 | 3.3 | 3.1 | 4.40 |
| **S2.3** | 9.1 | 3.4 | 3.3 | 4.22 |
| **AVERAGE** | 8.6 | 3.3 | 3.2 | 4.42 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 9.9 | 3.0 | 3.0 | 5.08 |
| **S3.2** | 9.8 | 3.2 | 3.2 | 5.11 |
| **S3.3** | 9.9 | 3.3 | 3.3 | 5.16 |
| **AVERAGE** | 9.9 | 3.2 | 3.2 | 5.12 |

- Vol.of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.1; S2 = 5.3; S4 = 5.4

**Table B3: HB 614 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 12.3 | 4.8 | 4.7 | 6.52 |
| **S1.2** | 12.3 | 4.7 | 4.7 | 6.72 |
| **S1.3** | 12.3 | 4.8 | 4.7 | 6.87 |
| **AVERAGE** | 12.3 | 4.8 | 4.7 | 6.70 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 11.0 | 3.3 | 3.3 | 4.73 |
| **S2.2** | 10.9 | 3.4 | 3.4 | 5.08 |
| **S2.3** | 10.9 | 3.5 | 3.4 | 5.01 |
| **AVERAGE** | 10.9 | 3.4 | 3.4 | 4.94 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 11.9 | 4.6 | 4.5 | 5.82 |
| **S3.2** | 11.9 | 4.5 | 4.5 | 5.79 |
| **S3.3** | 11.7 | 4.4 | 4.5 | 5.89 |
| **AVERAGE** | 11.8 | 4.5 | 4.5 | 5.83 |

- Volume of juice fermented: S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.3; S2 = 5.5; S3 = 5.4

**Table B4: HB 516 Fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 8.5 | 3.1 | 3.1 | 4.30 |
| **S1.2** | 9.7 | 2.4 | 2.4 | 4.51 |
| **S1.3** | 9.7 | 2.5 | 2.4 | 4.40 |
| **AVERAGE** | 9.3 | 2.7 | 2.6 | 4.40 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 9.7 | 2.4 | 2.4 | 5.34 |
| **S2.2** | 9.7 | 2.4 | 2.4 | 5.21 |
| **S2.3** | 9.7 | 2.5 | 2.4 | 5.53 |
| **AVERAGE** | 9.7 | 2.4 | 2.4 | 5.36 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 12.0 | 5.0 | 5.0 | 5.66 |
| **S3.2** | 12.1 | 5.1 | 5.0 | 6.00 |
| **S3.3** | 12.1 | 5.0 | 4.9 | 5.85 |
| **AVERAGE** | 12.1 | 5.0 | 5.0 | 5.84 |

- Volume of juice fermented : S1 = 200ml; S2 = 200ml; S3 =200ml
- pH of juice: S1 = 5.6; S2 = 6.0; S3 = 5.9

**Table B5: PHB 30079 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 10.0 | 3.9 | 3.7 | 4.73 |
| **S1.2** | 10.0 | 3.8 | 3.7 | 4.80 |
| **S1.3** | 10.0 | 3.8 | 3.7 | 4.77 |
| **AVERAGE** | 10.0 | 3.8 | 3.7 | 4.77 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 10.1 | 2.8 | 2.8 | 5.00 |
| **S2.2** | 10.2 | 3.0 | 3.0 | 5.21 |
| **S2.3** | 10.2 | 2.9 | 2.9 | 5.79 |
| **AVERAGE** | 10.2 | 2.9 | 2.9 | 5.33 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 10.0 | 3.0 | 2.9 | 3.30 |
| **S3.2** | 10.1 | 2.9 | 2.9 | 3.43 |
| **S3.3** | 10.0 | 2.9 | 2.9 | 3.59 |
| **AVERAGE** | 10.0 | 2.9 | 2.9 | 3.44 |

- Volume of juice fermented : S1 = 100ml; S2 = 100ml; S3 = 200ml
- pH of juice: S1 = 5.4; S2 = 6.0; S3 = 5.9

**Table B6: PHB 30G19 Fermentation data and yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 9.4 | 3.3 | 3.3 | 3.15 |
| **S1.2** | 9.3 | 3.2 | 3.2 | 3.29 |
| **S1.3** | 9.4 | 3.2 | 3.2 | 3.22 |
| **AVERAGE** | 9.4 | 3.2 | 3.2 | 3.22 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 8.8 | 2.3 | 2.4 | 5.48 |
| **S2.2** | 8.8 | 2.2 | 2.3 | 5.29 |
| **S2.3** | 8.7 | 2.3 | 2.2 | 5.97 |
| **AVERAGE** | 8.8 | 2.3 | 2.3 | 5.58 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 10.1 | 2.3 | 2.2 | 3.15 |
| **S3.2** | 10.0 | 2.1 | 2.1 | 3.55 |
| **S3.3** | 10.0 | 2.2 | 2.2 | 3.40 |
| **AVERAGE** | 10.0 | 2.2 | 2.2 | 3.37 |

- Volume of juice fermented : S1 = 100ml; S2 = 100ml; S3 = 200ml
- pH of juice: S1 = 5.4; S2 = 5.9; S3 = 6.0

**Table B7: MU 022 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 8.8 | 2.1 | 2.1 | 4.08 |
| **S1.2** | 8.7 | 2.2 | 2.1 | 4.30 |
| **S1.3** | 8.8 | 2.2 | 2.1 | 4.20 |
| **AVERAGE** | 8.8 | 2.2 | 2.1 | 4.21 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 9.7 | 3.4 | 3.4 | 4.80 |
| **S2.2** | 9.6 | 3.3 | 3.3 | 4.73 |
| **S2.3** | 9.6 | 3.3 | 3.3 | 4.77 |
| **AVERAGE** | 9.6 | 3.3 | 3.3 | 4.76 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 9.9 | 3.8 | 3.8 | 3.92 |
| **S3.2** | 9.9 | 3.6 | 3.7 | 4.51 |
| **S3.3** | 10.0 | 3.7 | 3.6 | 4.25 |
| **AVERAGE** | 9.9 | 3.7 | 3.7 | 4.23 |

- Volume of juice fermented : S1 = 200ml; S2 = 200ml; S3 =200ml
- pH of juice: S1 = 5.3; S2 = 6.0; S3 = 6.1

**Table B8: MU 017 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 8.8 | 2.5 | 2.5 | 3.94 |
| **S1.2** | 8.8 | 2.4 | 2.4 | 4.22 |
| **S1.3** | 8.8 | 2.2 | 2.2 | 4.08 |
| **AVERAGE** | 8.8 | 2.4 | 2.4 | 4.09 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 9.9 | 3.3 | 3.3 | 4.94 |
| **S2.2** | 9.9 | 3.3 | 3.3 | 5.01 |
| **S2.3** | 9.9 | 3.1 | 3.1 | 4.98 |
| **AVERAGE** | 9.9 | 3.2 | 3.2 | 5.00 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 9.1 | 3.6 | 3.7 | 3.30 |
| **S3.2** | 9.1 | 3.8 | 3.8 | 3.46 |
| **S3.3** | 9.1 | 3.8 | 3.8 | 3.62 |
| **AVERAGE** | 9.1 | 3.7 | 3.8 | 3.46 |

- Volume of juice fermented : S1 =100ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.5; S2 = 6.2; S3 = 6.1

**Table B9: Katumani fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 10.1 | 3.5 | 3.6 | 5.73 |
| **S1.2** | 10.1 | 3.5 | 3.5 | 5.69 |
| **S1.3** | - | - | - | - |
| **AVERAGE** | 10.1 | 3.5 | 3.6 | 5.71 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 14.3 | 5.5 | 5.5 | 8.95 |
| **S2.2** | 14.3 | 5.4 | 5.4 | 8.90 |
| **S2.3** | - | - | - | - |
| **AVERAGE** | 14.3 | 5.5 | 5.5 | 8.93 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 11.33 | 5.2 | 5.2 | 6.9 |
| **S3.2** | - | - | - | - |
| **S3.3** | - | - | - | - |
| **AVERAGE** | 11.33 | 5.2 | 5.2 | 6.9 |

- Vol. of juice fermented:S1 = 150ml; S2 = 150ml; S3=150ml
- pH of juice: S1 = 4.9; S2 = 5.1

**Table B10: DH01 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 10.1 | 4.2 | 4.1 | 6.84 |
| **S1.2** | 10.1 | 4.1 | 4.1 | 6.81 |
| **S1.3** | 10.1 | 4.1 | 4.1 | 6.87 |
| **AVERAGE** | 10.1 | 4.1 | 4.1 | 6.84 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 14.3 | 5.1 | 5.2 | 8.30 |
| **S2.2** | 14.3 | 5.5 | 5.4 | 7.80 |
| **S2.3** | 14.3 | 5.5 | 5.3 | 8.19 |
| **AVERAGE** | 14.3 | 5.4 | 5.3 | 8.10 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 12.3 | 5.2 | 4.8 | 6.38 |
| **S3.2** | 12.3 | 5.3 | 4.8 | 6.44 |
| **S3.3** | - | - | - | - |
| **AVERAGE** | 12.3 | 5.3 | 4.8 | 6.41 |

- Vol. of juice fermented:S1 = 150ml; S2 = 150ml; S3 = 200ml
- pH of juice: S1 = 5.1; S2 = 5.0; S3 = 5.0

**Table B11: DH02 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 10.1 | 3.2 | 3.1 | 5.29 |
| **S1.2** | 10.1 | 3.3 | 3.2 | 5.45 |
| **S1.3** | - | - | - | - |
| **AVERAGE** | 10.1 | 3.3 | 3.2 | 5.37 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 15.3 | 5.1 | 5.0 | 8.68 |
| **S2.2** | 15.3 | 5.9 | 6.0 | 8.62 |
| **S2.3** | - | - | - | - |
| **AVERAGE** | 15.3 | 5.5 | 5.5 | 8.65 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 11.0 | 4.8 | 4.2 | 5.30 |
| **S3.2** | 11.1 | 4.6 | 4.0 | 5.10 |
| **S3.3** | - | - | - | - |
| **AVERAGE** | 11.1 | 4.7 | 4.1 | 5.30 |

- Vol. of juice fermented:S1 = 200ml; S2 = 150ml;
- pH of juice: S1 = 4.6; S2 = 4.8; S3 = 5.0

**Table B12: HB 624 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 13.2 | 5.0 | 4.9 | 7.94 |
| **S1.2** | 13.2 | 5.0 | 5.0 | 8.10 |
| **S1.3** | 13.2 | 4.9 | 5.1 | 7.99 |
| **AVERAGE** | 13.2 | 5.0 | 5.0 | 8.01 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 12.2 | 4.7 | 4.7 | 6.21 |
| **S2.2** | 12.2 | 4.5 | 4.5 | 6.27 |
| **S2.3** | 12.2 | 4.7 | 4.6 | 6.33 |
| **AVERAGE** | 12.2 | 4.6 | 4.6 | 6.27 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 12.9 | 5.8 | 5.8 | 6.95 |
| **S3.2** | 12.9 | 5.6 | 5.5 | 7.00 |
| **S3.3** | 12.9 | 5.6 | 5.6 | 7.04 |
| **AVERAGE** | 12.9 | 5.6 | 5.6 | 7.0 |

- Vol. of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.1; S2 = 5.3; S3 = 5.4

**Table B13: HB 628 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 12.6 | 4.9 | 4.8 | 6.72 |
| **S1.2** | 12.6 | 4.3 | 4.4 | 6.78 |
| **S1.3** | 12.6 | 4.5 | 4.5 | 6.80 |
| **AVERAGE** | 12.6 | 4.6 | 4.6 | 6.77 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 12.4 | 4.6 | 4.8 | 6.01 |
| **S2.2** | 12.4 | 4.8 | 4.6 | 5.90 |
| **S2.3** | 12.4 | 4.0 | 4.1 | 6.02 |
| **AVERAGE** | 12.4 | 4.5 | 4.5 | 5.98 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 13.5 | 5.1 | 5.1 | 7.20 |
| **S3.2** | 13.5 | 5.1 | 5.0 | 7.15 |
| **S3.3** | 13.5 | 5.7 | 5.6 | 7.02 |
| **AVERAGE** | 13.5 | 5.3 | 5.2 | 7.12 |

- Vol.of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 4.9; S2 = 5.2; S3 = 5.3

**Table B14: HB520 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 13.6 | 4.8 | 4.8 | 8.69 |
| **S1.2** | 13.6 | 4.9 | 4.9 | 8.80 |
| **S1.3** | 13.6 | 4.9 | 4.8 | 8.84 |
| **AVERAGE** | 13.6 | 4.9 | 4.8 | 8.78 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 13.0 | 4.8 | 4.7 | 6.80 |
| **S2.2** | 13.0 | 4.3 | 4.4 | 6.61 |
| **S2.3** | 13.0 | 4.9 | 4.7 | 6.68 |
| **AVERAGE** | 13.0 | 4.7 | 4.7 | 6.70 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 12.0 | 4.4 | 4.4 | 7.02 |
| **S3.2** | 12.0 | 5.1 | 4.9 | 6.73 |
| **S3.3** | 12.0 | 5.0 | 5.0 | 6.90 |
| **AVERAGE** | 12.0 | 4.8 | 4.8 | 6.90 |

- Vol.of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.1; S2 = 5.3; S3 = 5.4

**Table B15: HB 625 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 12.8 | 5.0 | 4.8 | 8.21 |
| **S1.2** | 12.8 | 4.9 | 4.8 | 8.33 |
| **S1.3** | 12.8 | 5.0 | 4.9 | 8.27 |
| **AVERAGE** | 12.8 | 5.0 | 4.8 | 8.27 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 13.1 | 3.9 | 4.0 | 6.66 |
| **S2.2** | 13.1 | 4.9 | 4.4 | 6.40 |
| **S2.3** | 13.1 | 4.9 | 4.4 | 6.59 |
| **AVERAGE** | 13.1 | 4.9 | 4.4 | 6.55 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 13.5 | 4.6 | 4.5 | 7.31 |
| **S3.2** | 13.5 | 4.7 | 4.7 | 7.42 |
| **S3.3** | 13.5 | 4.6 | 4.5 | 7.65 |
| **AVERAGE** | 13.5 | 4.6 | 4.6 | 7.46 |

- Vol. of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.0; S2 = 5.1; S3= 5.1

**Table B16: HB 626 fermentation data and ethanol yield**

| Sample | Sugar content (Brix %) | | | Ethanol yield (% v/v) |
|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | |
| **Silking stage (S1)** | | | | |
| **S1.1** | 12.3 | 4.0 | 4.1 | 6.95 |
| **S1.2** | 12.3 | 4.1 | 4.0 | 6.87 |
| **S1.3** | 12.3 | 4.2 | 4.2 | 6.91 |
| **AVERAGE** | 12.3 | 4.1 | 4.1 | 6.91 |
| **Milk stage (S2)** | | | | |
| **S2.1** | 13.5 | 4.6 | 4.6 | 7.72 |
| **S2.2** | 13.5 | 4.4 | 4.4 | 7.59 |
| **S2.3** | 13.5 | 4.4 | 4.3 | 7.70 |
| **AVERAGE** | 13.5 | 4.5 | 4.4 | 7.67 |
| **Dry maize stage(S3)** | | | | |
| **S3.1** | 14.0 | 5.7 | 5.5 | 7.5 |
| **S3.2** | 14.0 | 5.3 | 5.3 | 7.3 |
| **S3.3** | 14.0 | 5.7 | 5.6 | 7.7 |
| **AVERAGE** | 14.0 | 5.6 | 5.5 | 7.5 |

- Vol.of juice fermented:S1 = 200ml; S2 = 200ml; S3 = 200ml
- pH of juice: S1 = 5.1; S2 = 5.0 S3 = 5.0

## APPENDIX C: DATA ON CONCENTRATION OF SPECIFIC SUGARS AS OBTAINED FROM THE HPLC ANALYSIS.

### Table C1: Fructose concentration in maize stalk juice

| Maize variety | Fructose | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Silking Stage (S1) | | | | Milk stage(S2) | | | | Dry maize stage (S3) | | | |
| | Area | concentration (mg/ml) | % concentration | actual %conc.* | Area | concentration (mg/ml) | % concentration | actual % conc. | Area | concentration (mg/ml) | % concentration | actual % conc. |
| PHB 30G19 | 1419023 | 25.0 | 2.5 | 5.0 | 986015 | 17.3 | 1.7 | 3.5 | 413593 | 7.1 | 0.7 | 1.4 |
| DLC | 784370 | 13.7 | 1.4 | 2.7 | 582442 | 10.1 | 1.0 | 2.0 | 581346 | 10.1 | 1.0 | 2.0 |
| MU03-022 | 1244234 | 21.9 | 2.2 | 4.4 | 1624496 | 28.6 | 2.9 | 5.7 | 525468 | 9.1 | 0.9 | 1.8 |
| MU03-017 | 1225450 | 21.5 | 2.2 | 4.3 | 685363 | 11.9 | 1.2 | 2.4 | 790549 | 13.8 | 1.4 | 2.8 |
| HB516 | 1013798 | 17.8 | 1.8 | 3.6 | 1070425 | 18.8 | 1.9 | 3.8 | 481862 | 8.3 | 0.8 | 1.7 |
| HB614 | 450354 | 7.8 | 0.8 | 1.6 | 445566 | 7.7 | 0.8 | 1.5 | 272998 | 4.6 | 0.5 | 0.9 |
| HB 513 | 999872 | 17.5 | 1.8 | 3.5 | 463172 | 8.0 | 0.8 | 1.6 | 229144 | 3.8 | 0.4 | 0.8 |
| PHB30079 | 1127037 | 19.8 | 2.0 | 4.0 | 952942 | 16.7 | 1.7 | 3.3 | 741288 | 12.9 | 1.3 | 2.6 |
| Katumani | 571313 | 9.9 | 1.0 | 2.0 | 355768 | 6.1 | 0.6 | 1.2 | 168773 | 2.0 | 0.2 | 0.4 |
| DH01 | 824599 | 14.4 | 1.4 | 2.9 | 395323 | 6.8 | 0.7 | 1.4 | 257278 | 3.1 | 0.3 | 0.6 |
| DH02 | 540227 | 9.4 | 0.9 | 1.9 | 586471 | 10.2 | 1.0 | 2.0 | 183057 | 2.2 | 0.2 | 0.4 |
| HB628 | 936727 | 16.4 | 1.6 | 3.3 | 344877 | 5.9 | 0.6 | 1.2 | 444085 | 5.3 | 0.5 | 1.1 |
| HB520 | 1008033 | 17.7 | 1.8 | 3.5 | 315666 | 5.4 | 0.5 | 1.1 | 168448 | 2.0 | 0.2 | 0.4 |
| HB624 | 1123698 | 19.7 | 2.0 | 3.9 | 219933 | 3.7 | 0.4 | 0.7 | 173222 | 2.1 | 0.2 | 0.4 |
| HB625 | 840876 | 14.7 | 1.5 | 2.9 | 343316 | 5.9 | 0.6 | 1.2 | 172002 | 2.1 | 0.2 | 0.4 |
| **HB626** | 998037 | 17.5 | 1.7 | 3.5 | 317955 | 5.4 | 0.5 | 1.1 | 174913 | 2.1 | 0.2 | 0.4 |

## Table C2: Glucose concentration in maize stalk juice

| Maize variety | Area (Glucose) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Silking Stage (S1) | | | | Milk stage(S2) | | | | Dry maize stage (S3) | | | |
| | Area | concentration (mg/ml) | %concentration | actual %conc. | Area | concentration (mg/ml) | %concentration | actual %conc. | Area | concentration (mg/ml) | %concentration | actual %conc. |
| PHB 30G19 | 1372795 | 29.1 | 2.9 | 5.8 | 999350 | 21.1 | 2.1 | 4.2 | 400522 | 8.2 | 0.8 | 1.6 |
| DLC | 823939 | 17.3 | 1.7 | 3.5 | 643601 | 13.4 | 1.3 | 2.7 | 603950 | 12.6 | 1.3 | 2.5 |
| MU03-022 | 1066665 | 22.5 | 2.3 | 4.5 | 1528543 | 32.4 | 3.2 | 6.5 | 555478 | 11.5 | 1.2 | 2.3 |
| MU03-017 | 1201638 | 25.4 | 2.5 | 5.1 | 668027 | 14.0 | 1.4 | 2.8 | 824731 | 17.3 | 1.7 | 3.5 |
| HB516 | 1064868 | 22.5 | 2.2 | 4.5 | 1059984 | 22.4 | 2.2 | 4.5 | 606394 | 12.6 | 1.3 | 2.5 |
| HB614 | 458072 | 9.5 | 0.9 | 1.9 | 439956 | 9.1 | 0.9 | 1.8 | 342953 | 7.0 | 0.7 | 1.4 |
| HB 513 | 934848 | 19.7 | 2.0 | 3.9 | 377122 | 7.7 | 0.8 | 1.5 | 234335 | 4.7 | 0.5 | 0.9 |
| PHB30079 | 1140366 | 24.1 | 2.4 | 4.8 | 962009 | 20.3 | 2.0 | 4.1 | 597211 | 12.4 | 1.2 | 2.5 |
| KATUMANI | 571705 | 11.9 | 1.2 | 2.4 | 433522 | 8.9 | 0.9 | 1.8 | 158270 | 2.2 | 0.2 | 0.4 |
| DH01 | 817418 | 17.2 | 1.7 | 3.4 | 452048 | 9.3 | 0.9 | 1.9 | 287243 | 3.9 | 0.4 | 0.8 |
| DH02 | 506587 | 10.5 | 1.0 | 2.1 | 593962 | 12.4 | 1.2 | 2.5 | 203437 | 2.8 | 0.3 | 0.6 |
| HB628 | 903427 | 19.0 | 1.9 | 3.8 | 387971 | 7.9 | 0.8 | 1.6 | 515796 | 7.0 | 0.7 | 1.4 |
| HB520 | 1102912 | 23.3 | 2.3 | 4.7 | 319288 | 6.5 | 0.6 | 1.3 | 245684 | 3.3 | 0.3 | 0.7 |
| HB624 | 1104526 | 23.3 | 2.3 | 4.7 | 241135 | 4.8 | 0.5 | 1.0 | 255449 | 3.5 | 0.3 | 0.7 |
| HB625 | 810194 | 17.0 | 1.7 | 3.4 | 291515 | 5.9 | 0.6 | 1.2 | 239113 | 3.3 | 0.3 | 0.7 |
| HB626 | 988933 | 20.8 | 2.1 | 4.2 | 405756 | 8.3 | 0.8 | 1.7 | 245188 | 3.3 | 0.3 | 0.7 |

**Table C3: Sucrose concentration in maize stalk juice**

| Maize variety | Area (Sucrose) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Silking Stage (S1) | | | | Milk stage(S2) | | | | Dry maize stage (S3) | | | |
| | Area | concentration (mg/ml) | %concentration | actual %conc. | Area | concentration (mg/ml) | %concentration | actual %conc. | Area | concentration (mg/ml) | %concentration | actual %conc. |
| PHB 30G19 | 105216 | 1.6 | 0.2 | 0.3 | 126834 | 2.0 | 0.2 | 0.4 | 1326596 | 22.4 | 2.2 | 4.5 |
| DLC | 2172642 | 36.9 | 3.7 | 7.4 | 1380923 | 23.4 | 2.3 | 4.7 | 1361546 | 23.0 | 2.3 | 4.6 |
| MU03-022 | 155000 | 2.4 | 0.2 | 0.5 | 144952 | 2.3 | 0.2 | 0.5 | 1689893 | 28.6 | 2.9 | 5.7 |
| MU03-017 | 122961 | 1.9 | 0.2 | 0.4 | 1169579 | 19.8 | 2.0 | 4.0 | 975162 | 16.4 | 1.6 | 3.3 |
| HB516 | 131710 | 2.0 | 0.2 | 0.4 | 306108 | 5.0 | 0.5 | 1.0 | 1482133 | 25.1 | 2.5 | 5.0 |
| HB614 | 2212757 | 37.6 | 3.8 | 7.5 | 1140983 | 19.3 | 1.9 | 3.9 | 1712153 | 29.0 | 2.9 | 5.8 |
| HB 513 | 1230088 | 20.8 | 2.1 | 4.2 | 1765049 | 29.9 | 3.0 | 6.0 | 1614624 | 27.4 | 2.7 | 5.5 |
| PHB30079 | 71374 | 1.0 | 0.1 | 0.2 | 273434 | 4.5 | 0.4 | 0.9 | 981205 | 16.5 | 1.7 | 3.3 |
| KATUMANI | 1056847 | 17.8 | 1.8 | 3.6 | 2040560 | 34.6 | 3.5 | 6.9 | 1986806 | 24.0 | 2.4 | 4.8 |
| DH01 | 628357 | 10.5 | 1.1 | 2.1 | 1495536 | 25.3 | 2.5 | 5.1 | 1909638 | 23.0 | 2.3 | 4.6 |
| DH02 | 406526 | 6.7 | 0.7 | 1.3 | 1958441 | 33.2 | 3.3 | 6.6 | 2200899 | 26.5 | 2.7 | 5.3 |
| HB628 | 958099 | 16.2 | 1.6 | 3.2 | 2720737 | 46.2 | 4.6 | 9.2 | 3559350 | 42.9 | 4.3 | 8.6 |
| HB520 | 1681393 | 28.5 | 2.8 | 5.7 | 2318093 | 39.4 | 3.9 | 7.9 | 3682098 | 44.4 | 4.4 | 8.9 |
| HB624 | 1622041 | 27.5 | 2.7 | 5.5 | 1568980 | 26.6 | 2.7 | 5.3 | 3801336 | 45.9 | 4.6 | 9.2 |
| HB625 | 672776 | 11.3 | 1.1 | 2.3 | 1636738 | 27.7 | 2.8 | 5.5 | 4862744 | 58.7 | 5.9 | 11.7 |
| HB626 | 1300185 | 22.0 | 2.2 | 4.4 | 2097334 | 35.6 | 3.6 | 7.1 | 4180551 | 50.4 | 5.0 | 10.1 |

*** concentration multiplied by 2 for all the specific sugars because a dilution by 2 was done on all the samples**

## APPENDIX D: SAMPLE CALCULATION FOR THE JUICE AND ETHANOL YIELDS

Dry Land Composite (DLC)

Date of sampling : S1 -20 / 05 / 08; S2- 16 /06/ 08; S3 – 22 / 07 / 08

**Table D1: DLC juice yield and sugar content**

| Sample | Height per stalk (cm) | | | | | | Average stalk height (cm) | Sample weight (kg) | Sample Juice yield (ml) | Sugar content (Brix %) | | | Average sugar content (Brix%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stalk 1 | Stalk 2 | Stalk 3 | Stalk 4 | Stalk 5 | Stalk 6 | | | | Reading 1 | Reading 2 | Reading 3 | |
| **Silking stage(S1)** | | | | | | | | | | | | | |
| **S1.1** | 74 | 113 | 102 | - | - | - | 96.3 | 0.71 | 200 | 10.9 | 10.8 | 9.8 | 10.9 |
| **S1.2** | 98 | 99 | 108 | - | - | - | 101.7 | 0.76 | 270 | 12 | 12.2 | 12 | 12.1 |
| **S1.3** | 81 | 95 | 89 | - | - | - | 88.3 | 0.62 | 150 | 11.7 | 11.3 | 11.6 | 11.5 |
| AVERAGES | | | | | | | 95.4 | 0.69 | 206.6 | | | | 11.5 |
| **Milk stage (S2)** | | | | | | | | | | | | | |
| **S2.1** | 79 | 136 | 115 | - | - | - | 110 | 0.87 | 265 | 10.5 | 10.7 | 10.6 | 10.6 |
| **S2.2** | 72 | 100 | 108 | - | - | - | 93.3 | 0.74 | 205 | 9.2 | 9.2 | 9.1 | 9.2 |
| **S2.3** | 122 | 123 | 112 | - | - | - | 119 | 0.96 | 265 | 9.5 | 9.8 | 9.7 | 9.7 |
| AVERAGES | | | | | | | 107.4 | 0.86 | 245 | | | | 9.8 |
| **Dry maize stage (S3)** | | | | | | | | | | | | | |
| **S3.1** | 73 | 95 | 54 | 104 | 66 | - | 78.4 | 1.05 | 150 | 12.3 | 12.5 | 12.2 | 12.4 |
| **S3.2** | 101 | 101 | 120 | 83 | 101 | - | 101.2 | 1 | 225 | 11.8 | 11.7 | 11.6 | 11.7 |
| **S3.3** | 70 | 94 | 88 | 95 | 84 | - | 86.2 | 0.84 | 140 | 12.7 | 12.3 | 12.2 | 12.4 |
| AVERAGES | | | | | | | 88.6 | 0.96 | 171.7 | | | | 12.2 |

**Silking stage (S1)**

Juice yield per sample, $J_s$ = ( 200 + 270 + 150) ÷ 3 = 206.6 ml / sample

But each sample has three stalks (n = 3),

hence juice yield per stalk ($j_s$) = $J_s$ ÷ n

= 206.6 ÷ 3 = 68.9ml / stalk

For DLC the plant spacing = (0.9 x 0.3) m and a planting of 2 plants per hole

Therefore the number of stalks per hectare, (N) = 2 [(100 ÷ 0.9) x (100 ÷ 0.3)] = 74059 stalks / ha.

The yield of juice per hectare (J), = $j_s$ x N = 68.9 x 74059 = 5103 litres / ha.

The average ethanol yield for S1, e = 5.9 %

Ethanol yield per hectare = eJ = 0.059 x 5103 = 301.1 litres / ha.

**Milk stage (S2)**

Juice yield per sample, $J_s$ = (265 + 205 + 265) ÷ 3 = 245.0ml / sample

But each sample has three stalks (n = 3),

Hence juice yield per stalk ($j_s$) = $J_s$ ÷ n = 245.0 ÷ 3 = 81.7 ml / stalk

For DLC the plant spacing = (0.9 x 0.3) m and a planting plants per hole

Therefore the number of stalks per hectare, (N) = 2 [(100 ÷ 0.9) x (100 ÷ 0.3)] = 74059 stalks / ha.

The yield of juice per hectare (J), = $j_s$ x N = 81.7 x 74059 = 6050.6 litres / ha.

The average ethanol yield for S2, e = 4.6 %

Ethanol yield per hectare = eJ = 0.046 x 6050.6 = 278.3 litres / ha.

**Dry maize stage (S3)**

Juice yield per sample, $J_s$ = (150 + 225 + 140) ÷ 3 = 171.7ml / sample

But each sample has three stalks (n = 5),

Hence juice yield per stalk ($j_s$) = $J_s$ ÷ n = 171.7 ÷ 5 = 34.3ml / stalk

For DLC the plant spacing = (0.9 x 0.3) m and a planting plants per hole

Therefore the number of stalks per hectare, (N) = 2 [(100 ÷ 0.9) x (100 ÷ 0.3)] = 74059 stalks / ha.

The yield of juice per hectare (J), = js x N = 34.3 x 74059 = 2540.2 litres / ha.

The average ethanol yield for S3, e = 5.09 %

Ethanol yield per hectare = eJ = 0.0509 x 2540.2 = 129.3litres / ha.

A density bottle (50ml) was used to determine the specific gravity of the distillates at $20^0$c.at the three stages. Weights of the distillates and distilled water also at $20^0$c were used to compute the densities and hence the specific gravity (sg).

sg = density of sample ÷ density of water ( at the same temperature) but, density = mass ÷volume; and volume in this case is constant

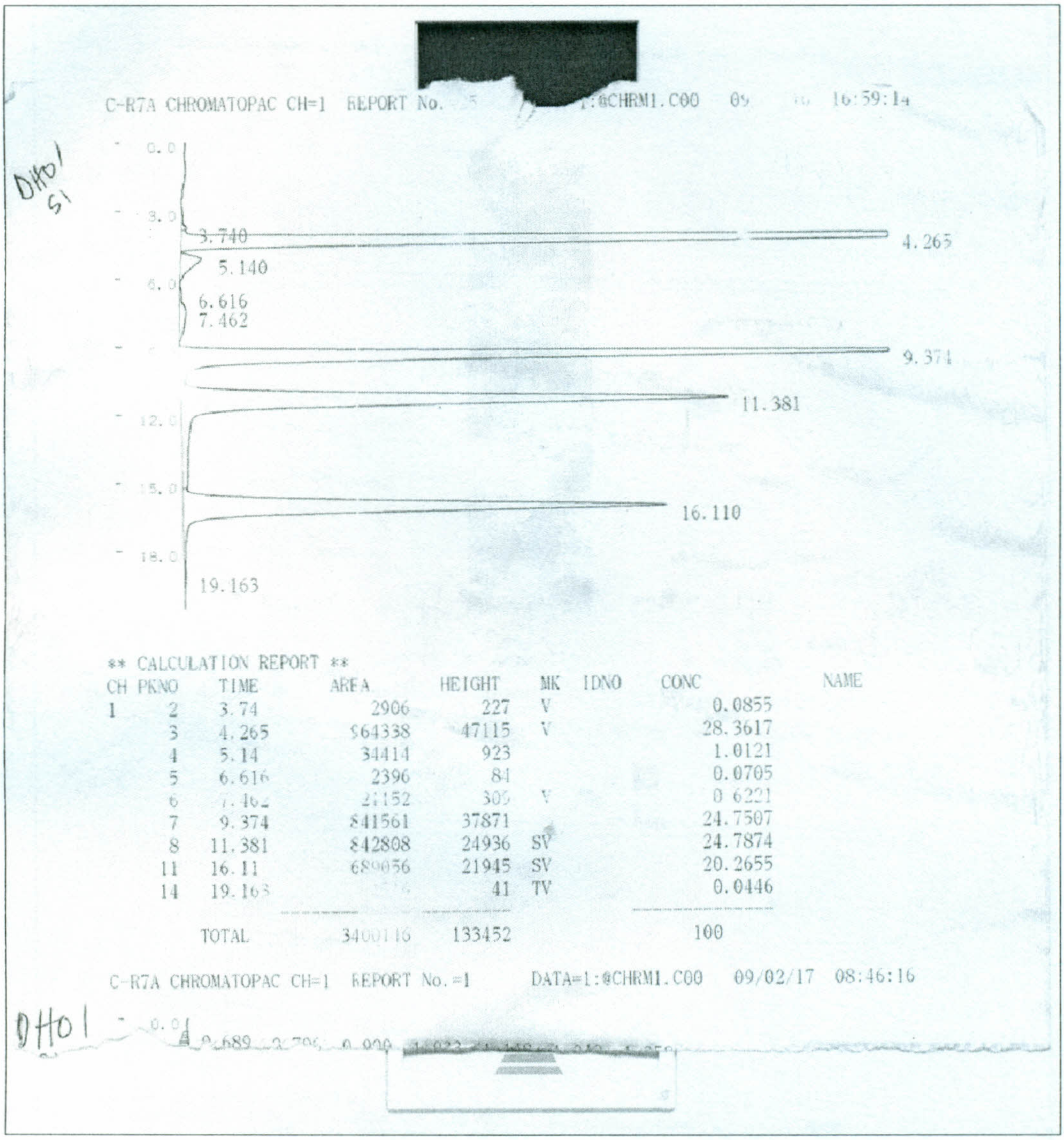
Hence, sg =mass of sample ÷ mass of water

**Table 6: Determination of alcohol content**

| Sample | S1 | S2 | S3 |
|---|---|---|---|
| Wt. of density + bottle | 81.5192 | 81.6189 | 81.8069 |
| Wt. of bottle | 30.1664 | 30.1664 | 30.5779 |
| Wt. of sample | 51.3528 | 51.4525 | 51.2310 |
| Wt. of bottle + water | 81.9398 | 81.9398 | 82.1634 |
| Wt. of water | 51.7734 | 51.7734 | 30.5779 |
| Specific gravity = wt. of sample / wt. of water | 0.9919 | 0.9938 | 0.9931 |
| % v/v alcohol content | 5.8 | 4.4 | 5.0 |

This was done in triplicate and average obtained. The alcohol content (% v/v) was read direct from a table of alcohol relationship with specific gravity at $20^0C$ ((Pearson, 1970; pg340)

# APPENDIX E: CHROMATOGRAM FOR DH01 SILKING STAGE (S1)




** CALCULATION REPORT **

| CH | PKNO | TIME | AREA | HEIGHT | MK | IDNO | CONC | NAME |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3.74 | 2906 | 227 | V | | 0.0855 | |
| | 3 | 4.265 | 964338 | 47115 | V | | 28.3617 | |
| | 4 | 5.14 | 34414 | 923 | | | 1.0121 | |
| | 5 | 6.616 | 2396 | 84 | | | 0.0705 | |
| | 6 | 7.462 | 21152 | 305 | V | | 0.6221 | |
| | 7 | 9.374 | 841561 | 37871 | | | 24.7507 | |
| | 8 | 11.381 | 842808 | 24936 | SV | | 24.7874 | |
| | 11 | 16.11 | 689056 | 21945 | SV | | 20.2655 | |
| | 14 | 19.163 | [illegible] | 41 | TV | | 0.0446 | |
| | | TOTAL | 3400116 | 133452 | | | 100 | |

Figure E1: Chromatogram for DH01 silking stage

# APPENDIX F: CHROMATOGRAM FOR STANDARD SUGARS

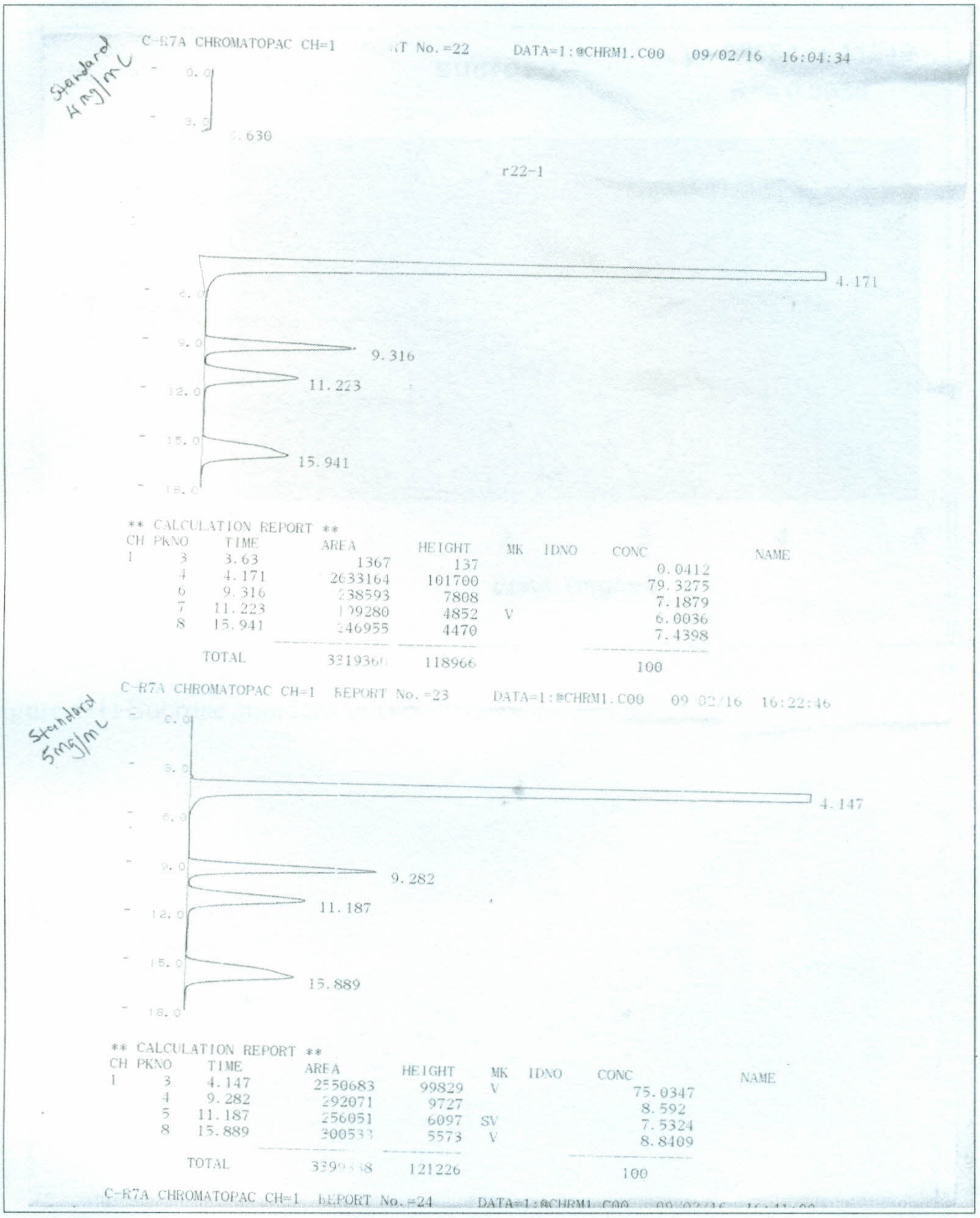


Figure F1: Chromatogram for standard sugars

# APPENDIX G: STANDARD CURVES FOR SUCROSE, FRUCTOSE AND GLUCOSE

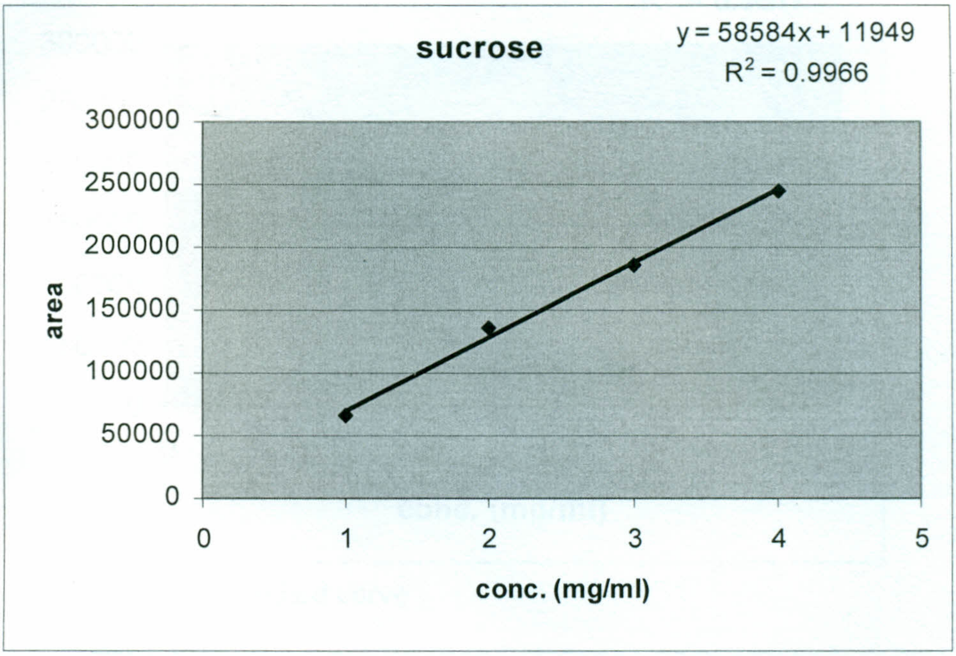



Figure G1: Sucrose standard curve

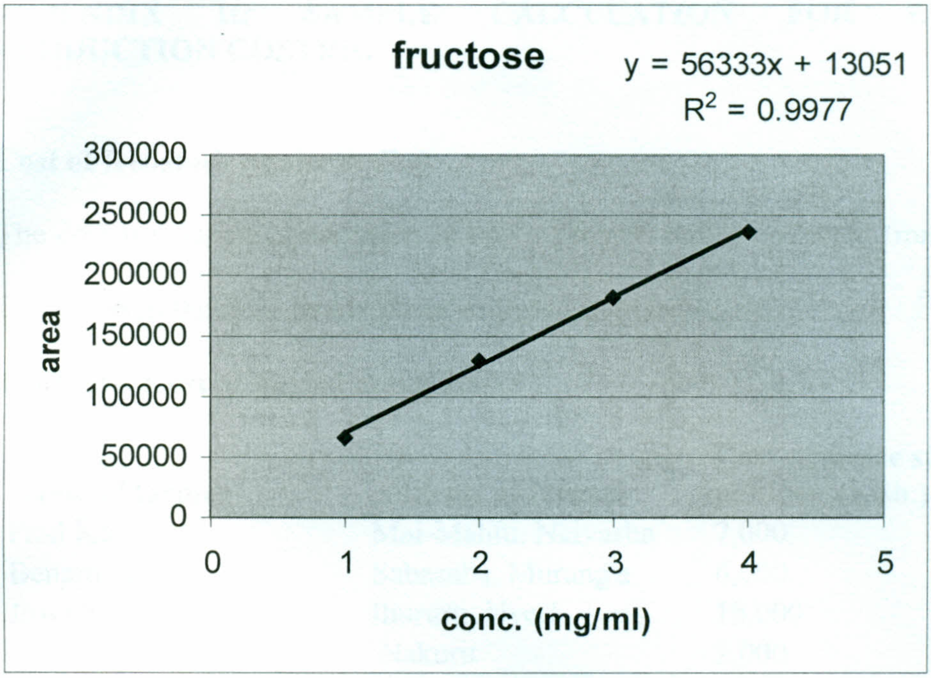



Figure G2: Fructose standard curve

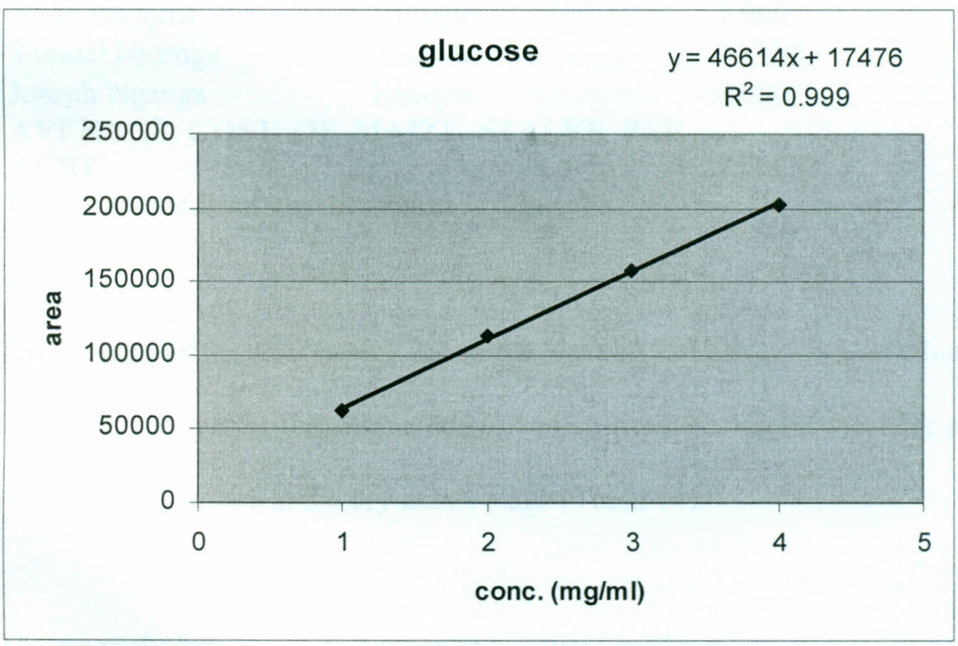



Figure G3: Glucose standard curve

## APPENDIX H: SAMPLE CALCULATION FOR ETHANOL PRODUCTION COSTING

### Cost of feedstock (maize stalks)

The cost was taken as the mean of cost of maize stalks, collected from different farmers as in the table below; Data collected in March 2010

**Table H1: Cost of buying maize stalks**

| Name of farmer | Address of farmer | Cost of maize stalks per acre (KSh.) |
|---|---|---|
| Paul Kiriu | Mai-Mahiu, Naivasha | 7,000 |
| Benard Gitau | Sabasaba, Murang'a | 6,000 |
| Joseph Ndirangu | Ihururu, Nyeri | 10,000 |
| John Kahura | Nakuru | 2,000 |
| James Gitau | Nairobi | 8,000 |
| David Njaraganu | Kikuyu | 8,000 |
| Alice Wanjiru | Kikuyu | 7,000 |
| Samuel Njoroge | Kikuyu | 10,000 |
| Joseph Nganga | Kikuyu | 8,000 |
| **AVERAGE COST OF MAIZE STALKS PER ACRE** | | **7333.33** |

(Data obtained from questionnaires – Appendix J)

The Maize variety selected for economic analysis is HB625 with an ethanol yield 917.5 litre/hectare at the silking stage, 1445.5 litres/hectare at the milk stage and 825.04 litres/hectare at the dry maize stage (Table 14).

The ethanol yield has been determined in litres per hectare.

1 hectare = 2.5 acres

Therefore; Cost of maize stalks per hectare = KSh. (7333.33x 2.5) = 18,333.33

And the cost of maize stalks required to make 1litre ethanol is as follows:

Calculated cost of maize stalks per litre of ethanol at the silking stage is; = 18,333.33 ÷917.5 = KSh.19.98

Calculated cost of maize stalks per litre of ethanol at the milk stage is; =18,333.33 ÷1445.5 = KSh.12.68

Calculated cost of maize stalks per litre of ethanol at the dry maize stage is; = KSh. (18,333.33 ÷ 825.0) = KSh. 22.22

**Cost of processing ethanol from the feedstock**

The cost of processing ethanol from the feedstock consists of the cost of crushing the maize stalks to obtain the maize stalk juice and the cost of processing the maize stalk juice into ethanol.

**i) The cost of crushing the stalks per litre of juice obtained.**

For the three roller squeezer used, the consumption of electric power per ton of sorghum stalks is 10.8kiloWatt (UNDP, 1994)

For HB 625, the average stalk weight in silking stage =0.41kg/stalk, at the milk stage = 0.54 kg/stalk and at the dry maize stage = 0.37kg/ stalk (Table 4)

The number of stalks per hectare = 106,640

Total weight of the stalks per hectare at the silking stage is = (0.41 x 106640) = 43,722.4Kg = 43.72 tons

And the power required to crush this is; = 43.72 x 10.8 = 472.18kW

Total weight of the stalks per hectare at the milk stage is = (0.54 x 106640) = 57,585.6Kg = 57.59 tons

And the power required to crush this is; = 57.59 x 10.8 = 622.0kW

Total weight of the stalks per hectare at the dry maize stage is = (0.37 x 106640) = 39,456.8Kg = 39.46 tons

And the power required to crush this is; = 39.46 x 10.8 = 426.17kW

But the yield of ethanol per hectare is 917.5litres/hectare at the silking stage, 1445.5litres/hectare at the milk stage and 825.0litres/hectare at the dry maize stage.

Therefore, Energy for squeezing out juice per litre of ethanol produced is;

At the silking stage; = (472.18÷917.5) = 0.51kW per litre of ethanol produced

At the milk stage; = (622.0 ÷1445.5) = 0.43kW per litre of ethanol produced

At the dry maize stage; = (426.17÷825.5) = 0.52 kW per litre of ethanol

Since year 2008 to date, the price of electricity has been averaging at KSh. 12 per kWh (ESA BMO, 2009).

Assuming one hour duration for crushing 1ton of stalks;

The cost of crushing the stalks to give 1 litre ethanol at the silking stage is, = KSh. (0.51 x 12) = KSh. 6.12

The cost of crushing the stalks to give 1 litre ethanol at the milk stage is = KSh. (0.43 x 12) = KSh.5.16

The cost of crushing the stalks to give 1 litre ethanol at the dry maize stage = KSh. (0.52x 12) = KSh.6.24

ii) **Cost of processing the maize stalk juice into ethanol**

The cost of processing the maize stalk juice into ethanol through fermentation and distillation was adopted from the Agro-Chemicals and Food Industries Ltd.

**Table H2: Cost for production per unit liter of neutral spirit**

| | Jun-09 | Dec-08 | Mar-07 | Dec-06 |
|---|---|---|---|---|
| **Variable costs** | | | | |
| Molasses | 13.04 | 11.87 | 8.79 | 8.98 |
| Chemicals | 1.88 | 2.06 | 1.06 | 1.12 |
| Electricity | 1.87 | 2.07 | 1.22 | 1.38 |
| Transport | 0 | 0 | 0 | 0 |
| Storage/handling | 0 | 0 | 0 | 0 |
| Steam | 5.92 | 7.74 | 4.48 | 4.39 |
| | **22.71** | **23.74** | **15.55** | **15.87** |
| **Fixed costs** | | | | |
| Salaries, wages &benefits | 9.09 | 9.28 | 7.82 | 7.09 |
| Administrative expenses | 6.16 | 5.72 | 5.04 | 6.93 |
| Interest & finance charges | -2.4 | -3.85 | 0.03 | 0.04 |
| Repairs and maintenance | 2.21 | 1.96 | 2.1 | 1.93 |
| | **15.06** | **13.11** | **14.99** | **15.99** |
| **Depreciation** | 3 | 4.44 | 4.83 | 3.25 |
| | **40.77** | **41.29** | **35.37** | **35.11** |
| **GoK converted loan interests** | 11.7 | 17.32 | 13.3 | 17.93 |
| **Total cost** | **52.47** | **58.61** | **48.67** | **53.04** |
| Realization | 63 | 63 | 55 | 55 |

*Source: Management accounts of ACFC*
*GoK- Government of Kenya.*

The cost of processing is taken as the cost of processing ethanol from molasses as in the table above for the year 2009 since molasses compares with the maize stalk juice. The cost of molasses is subtracted and substituted with the cost of maize stalks.

Therefore the cost of processing ethanol from maize stalk juice as per the data for year 2009 = Total cost of processing ethanol from molasses – cost of molasses = KSh. (52.47 – 13.04) = KSh. 39.43

Therefore: Total cost of processing ethanol from maize stalks is; = purchase cost of the maize stalks / hectare + cost of crushing maize stalks per hectare + cost of processing ethanol from maize stalk juice

At the silking stage the cost = KSh. (19.98+6.12+ 39.43) = KSh.65.53

At the milk stage the cost = KSh. (12.68+5.16 + 39.43) = KSh.57.27

At the dry maize stage the cost = KSh. (22.22 + 6.24 + 39.43) = KSh.67.89

**Estimated sale price per litre of the ethanol**

The projected sale price per litre of ethanol is 120% of the product cost of production (Peters and Timmerhaus, 1980), hence the projected sale price at each stage is as follows;

Silking stage = 120% of KSh.65.53 = KSh. (1.20 x 65.53) = KSh.78.64

Milk stage = 120% of 57.27 = KSh. (1.20 x 57.27) = KSh.68.72

Dry maize stage = 120% of 67.89 = KSh. (1.20 x 67.89) = KSh. 81.47

**Estimated sale price of the 10% ethanol 90% gasoline blend (E10) and kerosene fuel**

The current average retail price of unleaded petrol (gasoline) = KSh.86.96

Gasoline proportion cost in the E10; = 90% of the current retail price = KSh. (0.9 x 86.96) =KSh. 78.26

The cost of the ethanol / gasoline blend was computed for the three cases i.e. if ethanol was made from maize stalks harvested at the silking stage, at the milk stage and at the dry maize stage.

The current retail price for gasoline in Nairobi area is as tabulated below;

**Table H3: Pump price for gasoline and kerosene in Nairobi**

| Petrol station | Location | Cost of unleaded petrol (KSh.) | Cost of kerosene (KSh.) |
|---|---|---|---|
| National oil | Outer-ring road | 84.30 | 62.00 |
| Total Kenya | Outer-ring road | 83.70 | 61.50 |
| Kobil | Airport North road | 83.60 | 61.90 |
| Oil-Libya | Mombasa road | 88.90 | 64.50 |
| Kenol | Mombasa road | 88.90 | 64.00 |
| Total Kenya | Mombasa road | 88.70 | 64.90 |
| Caltex | Mombasa road | 88.70 | 64.90 |
| Shell BP | Mombasa road | 88.90 | 63.90 |
| **Average price** | | **86.96** | **63.45** |

*(As per survey done on March 24, 2010)*

At the silking stage the ethanol proportion cost is; = 10 % of sale price of ethanol at that stag = 10% of = KSh.( 0.1 x 78.64) = KSh.7.86

Therefore the estimated cost of 1litre of the blend is; = cost of the ethanol proportion and the cost of the gasoline proportion = 7.86+78.26 = KSh.86.12

At the milk stage the ethanol proportion cost is; = 10% of sale price of ethanol at that stage = 10% of 68.72 = KSh.( 0.1 x 68.72) = KSh.6.87

Therefore the estimated cost of 1litre of the blend is; = cost of the ethanol proportion and the cost of the gasoline proportion = 6.87 +78.26 = KSh.85.13

At the dry maize stage the ethanol proportion cost is; = 10% of sale price of ethanol at that stage = 10% of 81.47 = KSh.( 0.1 x 81.47) = 8.15

Therefore the estimated cost of 1litre of the blend is; = cost of the ethanol proportion and the cost of the gasoline proportion = 8.15 +78.26 = KSh.86.41

## APPENDIX J: QUESTIONNAIRE FOR FARMERS ON COST OF ANIMAL FODDER.

1. Name of farmer:.........................................................................

2. Address of farmer:……………………………………………………

3. Types of animals kept:………………………………………………

4. Number of cows kept:…………………………………………………

5. Type of fodder used:

i)……………………………………

ii)…………………………………..

iii)…………………………………..

iv)…………………………………..

6. Approximate cost of each fodder named in 5 above:

i)…………………

ii)…………………

iii)…………………

iv)…………………

7. Do you feed your animals on maize stalks

a) Yes

b) No

8. What is the source of your maize stalks

9. In what unit is the maize stalks sold

a) Heaps

b) Acreage

10. What is the cost of maize stalks per acreage

a) Dry maize stalks

b) Green Maize stalks

11) Any other comment

**APPENDIX K**

READINGS OF MONTHLY RAINFALL TOTALS IN MILLIMETRES

| NAME | YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KABETE AGROMET STATION | 2008 | 51.4 | 151.9 | 178.1 | 156.5 | 19 | 5.7 | 64.3 | 9.1 | 47.4 | 165.1 | 191.6 | 5.3 |
| KABETE | 2009 | 42.8 | 18.1 | 76.6 | 69.2 | 168.3 | 43.3 | 6.8 | 2.4 | 6.3 | 141.8 | 110.2 | 185.7 |
| KATUMANI EXP. RES. STATION. | 2008 | 117.4 | 7.3 | 73.0 | 129.3 | 4.5 | 0.3 | 1.3 | 0.2 | 9.1 | 23.9 | 122.8 | 39.9 |
| KATUMANI EXP. RES. STATION. | 2009 | 74.2 | 26.3 | 3.2 | 145.4 | 29.7 | 5.2 | 0.0 | 0.0 | 1.2 | 41.3 | 34.4 | 136.7 |

Kenya Meteorological Department Database