MIDLANDS STATE UNIVERSITY

SUITABILITY OF YELLOW MAIZE AS AN ALTERNATIVE TO WHITE MAIZE AS AN ADJUNCT IN LAGER BEER BREWING

BY

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ABSTRACT

Yellow maize is used as a raw material in many food industries but its use as an adjunct in beer brewing has not received much attention. This study was carried out at Delta Beverages Southerton Plant, Harare, to determine the suitability of yellow maize as an adjunct in larger beer brewing in terms of proximate analysis of its milled grits and wort analysis. The proximate composition of the yellow maize milled grits was determined through analysis of moisture content, gelatinization temperature, fat/oil content, protein content, limit of extract and fermentability-alcohol content. The wort characterization of the yellow maize milled grits was done through analysis of wort gravity, starch presence and colour of cooked maize grits. Wort gravity (15.72^0 Plato) and colour of cooked maize grits of yellow maize was high compared to wort gravity (15.65^0 Plato) and colour of cooked maize grits of white maize. Yellow maize grits had a higher starch, content than white maize making it a better alternative since wort of a higher sugar content produces beer with a higher alcohol percentage. Protein content and moisture content of yellow maize (9% and 12%, respectively) were similar to those of white maize (8.46%, and 12.27%, respectively) and they were within acceptable ranges for lager beer manufacturing. Undesirable properties of yellow maize grits including high fat content, colour and gelatinization temperatures were recorded but they are insignificant since they can be managed during the brewing process. From the wort and proximate analysis done, yellow maize can substitute for white maize in lager beer brewing.

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DEDICATIONS

This report is dedicated to very imsportant people in my life starting with my loving family who have inspired me in every way. I am very grateful to have been involved in their lives. I also want to thank my friends from college, for their collective support and inspiration up to this end.

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CHAPTER 1: INTRODUCTION

1.1 Background of study

Lager beer brewing is the production of beer through steeping a starch source from cereal grains in water then fermenting with yeast (Briggs, 1998). This is done through addition of adjuncts (alternative sources of sugar used in brewing) to malt (a cereal grain, usually barley, that is kiln-dried after having been germinated by soaking in water; used especially in brewing and distilling). Adjuncts are materials, other than malt, from which extract can be sourced (Briggs, 1998; Byrne and Letters, 1992; Letters, 1990; Lloyd, 1986, 1988a, 1988b; Martin, 1978; Stowell, 1985). They are used because they yield less expensive extract than malt and/or impart desirable characteristics to the lager beer (Bamforth, 2003). For example, they may dilute the levels of soluble nitrogen and polyphenolic tannins in the wort, allowing the use of high-nitrogen (protein rich) malts and the production of beer less prone to form haze (Briggs, 1998). Some adjuncts enhance head formation and retention.

The main drivers for the usage of brewing adjuncts are low cost of raw materials, together with opportunities of increasing product output capacity without the necessity of increasing brewhouse capacities (addition of syrups). In addition, usage of certain adjuncts has offered the brewer more control over product quality with regard to flavour, colour and colloidal stability (Briggs, 1998). Furthermore, governmental political decisions have encouraged the use of adjuncts. For example, manufacture of lager beer from unmalted sorghum and maize in Nigeria (Hallgren, 1995; Little 1994), manufacture of barley beer in Kenya (Cege *et al*., 1999) and more recently the manufacture of happoshu in Japan (Shimizu *et al*., 2002). Additionally, recent research efforts (Brauer *et al*., 2005; NicPhiarais *et al*., 2005) have concentrated on developing alternative beers and cereal-based beverages with the aim of fulfilling current consumers' health needs and expectations. Two such beverages where both traditional and non-traditional adjunct materials will play an important role in their recipe formulations (Goode and Arendt, 2005) are gluten-free beers and health promoting functional beers.

The amounts of adjuncts used vary widely. In some places their use is forbidden. In North America 60% of the extract in a brew may be derived from adjuncts, while elsewhere 10-20% is more usual (Briggs *et al*., 1981). It is feasible to make beers with up to 95% of the grist being raw barley (Briggs *et al*., 1981; Wieg, 1973; Wieg, 1987). The choice of adjunct(s) requires care. The material chosen must be regularly available in adequate amounts and be of good quality (Wieg, 1973). The use of this material must enhance, or at least not reduce, the quality of the beer being made. It is difficult to switch between different kinds of adjunct. Apart from the risk of altering the nature of the beer, changing adjuncts may require alterations in the brewery equipment (Wieg, 1987). For example, the handling plant needed for syrups is completely different from that needed for any mash tun adjunct and the equipment needed to handle flours; flakes and grits are all different.

Maize is probably the most popular grain adjunct in the world and is certainly one of the most versatile (Hallgren, 1995). In Zimbabwe white maize is the most preferred variety for use in brewing and is also popular with other food industries in which it is used to make products such as corn starch, breakfast cereals, corn oil, and maize meal (Piha, 1993). Moreover, white maize is the staple food in Zimbabwe and is consumed in different recipes (milled or unmilled) including sadza from maize meal. This importance of the white maize results in high demand for it throughout the country against its limited supply (Hallgren, 1995).

The shortage of white maize does not only lead to food insecurity in the country but also affect beer producing companies since maize is their main adjunct (Piha, 1993).Therefore there is need to look for alternatives adjuncts to white maize in beer brewing.

1.2 Justification

Currently, the leading lager beer brewer in Zimbabwe is using white maize grits as the only source of corn adjuncts (SABMiller manual, 2000). But maize is expensive because it is in short supply as it the staple food the majority of the population and is in demand by other food manufacturing industries (Piha, 1993). However, there are other varieties like yellow, red and purple corn available in Zimbabwe that can potentially be utilized as adjuncts to reduce the demand for white maize.

Yellow maize is a drought-resistant crop, which can do very well even in agro-ecological regions that receive insufficient rainfall (Challinor, 2007). In addition, yellow maize is a pest resistant crop, which makes it a more reliable crop that produces better yields with less input (money, pesticides and others) (Piha, 1993). This study aids to reduce the demand for white maize, fulfil current consumers' health needs and expectations and in addition this offers the brewer more control over product quality with regard to flavour, colour and colloidal stability.

1.3 Objectives

The main objective of this study was to assess the suitability of yellow maize as an alternative adjunct to white maize in lager beer brewing. Specifically this study sought to:

(1) evaluate and compare the characteristics wort produced from yellow maize and white maize

(2) perform and compare the proximate analysis of yellow and white maize grits, and

(3) assess the suitability of yellow maize as an adjunct based on proximate analysis and wort characteristics.

CHAPTER 2: LITERATURE REVIEW

2.1 Adjuncts

Adjuncts are unmalted grains such as corn, rice, rye, oats, barley, and wheat or grain products used in brewing beer and they can be solids or liquids which supplement the main mash ingredient (such as malted barley), often with the intention of cutting costs, but sometimes to create an additional feature, such as better foam retention, flavours or nutritional value or additives (SABMiller manual, 2000).

Typically, adjuncts contribute no enzyme activity to the mash, which can pose problems. The major benefits of adjunct use are that they contribute little soluble nitrogen, whilst purchase cost is usually reduced compared to malted barley (Briggs *et al*., 1981). Huge efforts are expended in improving adjunct performance and examining their contribution to final beer characteristics. In general, maize will give beer a fuller flavour than wheat, which imparts dryness, whilst barley supplies a stronger harsher flavour. Technically both wheat and barley can considerably improve the head retention of a product. The most commonly used adjunct materials worldwide are maize (46% of total adjunct use), rice (31%), barley (1%), and sugars and syrups (22%). Other materials are also used, for instance potato and soya beans, (Briggs *et al*, 1981).

Table 2.1.1 Types of brewing adjuncts

Adjunct Type	Adjunct Type
Basic raw cereal	Barley, wheat
Raw grits	Maize, rice, sorghum
Flakes	Maize, rice, barley, oats
Torrified/Micronised	Maize, barley, wheat
Flour/ Starch	Maize, wheat, rice, potato, sucrose
Syrup	Maize, wheat, barley, potato, sucrose
Malted cereals other than barley	Wheat, oats, rye, sorghum

2.1.2 Adjunct properties

The processing properties of adjuncts are related to their structure and chemistry. There are 6 major adjunct attributes that affect their use during brewing:

(1) decreased protein levels increase beer stability (by lowering haze potential) whilst reducing the capacity for microbial infection, therefore improving shelf life.

(2) diminished levels of lipid materials abate staling reactions and guard against loss of head retention.

(3) less cell wall material reduces b-glucan and pentosan content and improving wort viscosity.

(4) different proteins and their proportions present, improve head retention.

(5) differing starch gelatinisation temperatures can impose additional processing steps.

(6) altered fermentable sugar spectrums affect product flavour profiles.

2.1.3 Adjunct protein

Brewers mostly, only require protein derived from the grist for yeast nutrition. Diminished cereal protein levels in the wort reduce haze potential and susceptibility to microbial infection. Unfortunately, very rarely do adjuncts only supply sufficient protein for yeast fermentation. Wheat starch has the lowest protein levels, of the cereal adjuncts, and would meet the brewers' requirements. However, the wheat protein gluten is far more soluble than the barley protein hordein, and consequently, can cause brewhouse problems when used at lower concentrations. For these reasons, wheat is not primarily used as a source of starch. In addition to gluten, wheat also contains high levels of glycoproteins. These high molecular weight hydrophobic polypeptides act to stabilise beer foam (or head) by interacting with other polymers derived from hops. By using large quantities of wheat adjunct in the grist, the need to use synthetic head stabilisers such as Propylene Glycol Alginate (PGA) is avoided. Generally, the protein contributed to the wort from adjunct addition is insignificant, resulting in a linear dilution of wort free amino nitrogen (FAN). This dilution is accentuated further as malt proteases will not degrade unmalted cereals. Dilution of wort amino acids can be detrimental to yeast, critically forcing the yeast to anabolically synthesise the deficit. This can give rise to the production of unwanted flavours, such as diacetyl, a by-product of anabolic amino acid synthesis. This occurrence is most common with the use of large quantities of high glucose sugar and syrup adjuncts.

2.1.4 Adjunct lipid

The lipid content of the cereal is important and should be limited to prevent the occurrence of staling reactions, whilst defending against loss of head retention. The lipid materials are oxidised during brewhouse procedures, generating “off-flavours”. The lipids interact with the hydrophobic polypeptides within the head breaking their conformational structure, causing foam collapse. A reduction of lipid material can be achieved using grits (pure endosperm particles) and by removing the germ from the grain.

2.2 Description of yellow maize

Yellow maize is a cereal grain of the kingdom plantae and genus, *Zea*. The binomial name for maize in general is *Zea mays* L. (Sprague, 1977). The leafy part of the cereal plant produces ears which contain seeds called kernels. The kernel has a pericarp of the fruit fused with the seed coat referred to as the caryopsis and the entire kernel is referred to as the maize seed (Bonsembiante, -1983). The maize seed structure (Fig 2.2.1).

2.3 Commercial production of maize grits

Maize kernels are screened and conditioned using hot water or steam to loosen the germ and the bran. After conditioning, the grain is degermed and the husk is separated by means of aspirators. Drying follows immediately to reduce the moisture content to about 15% after which the grain is sifted. It is then subjected to milling to produce about 40% grits. The germs separated are dried and passed through an expeller to produce the corn oil (Johnson, 1991).

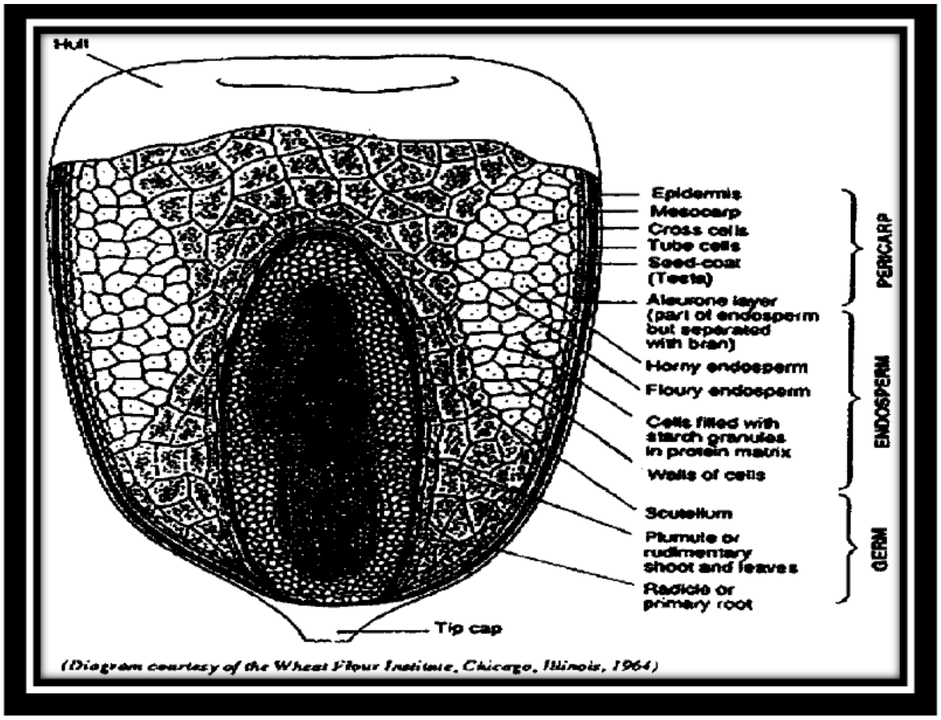

Figure 2.2.1 Maize kernel structure, adapted from (http://www.fao.org)

2.4 Analyses done on white maize grits and their importance

2.4.1 Moisture

Moisture content should not be too low or too high. Higher moisture content promotes growth of moulds, like aflatoxins, on stored maize in the silos ((Brookes and Philliskirk, 1987; South, 1992). In the UK the grain will be inspected to check that it is predominantly (e.g., >97%) of one specified variety, that its viability or germinative capacity which is checked by tetrazolium staining is equal to or exceeds the specified limit (at least 98%) and that the protein content (6.25%) is within specified limits (South, 1992). Grain moisture is usually checked using near-infra-red spectroscopy (NIR), but slower methods may be used. The grains will also be checked for `pre-germination', since grain that has already started to germinate will not keep or malt well (South, 1992).

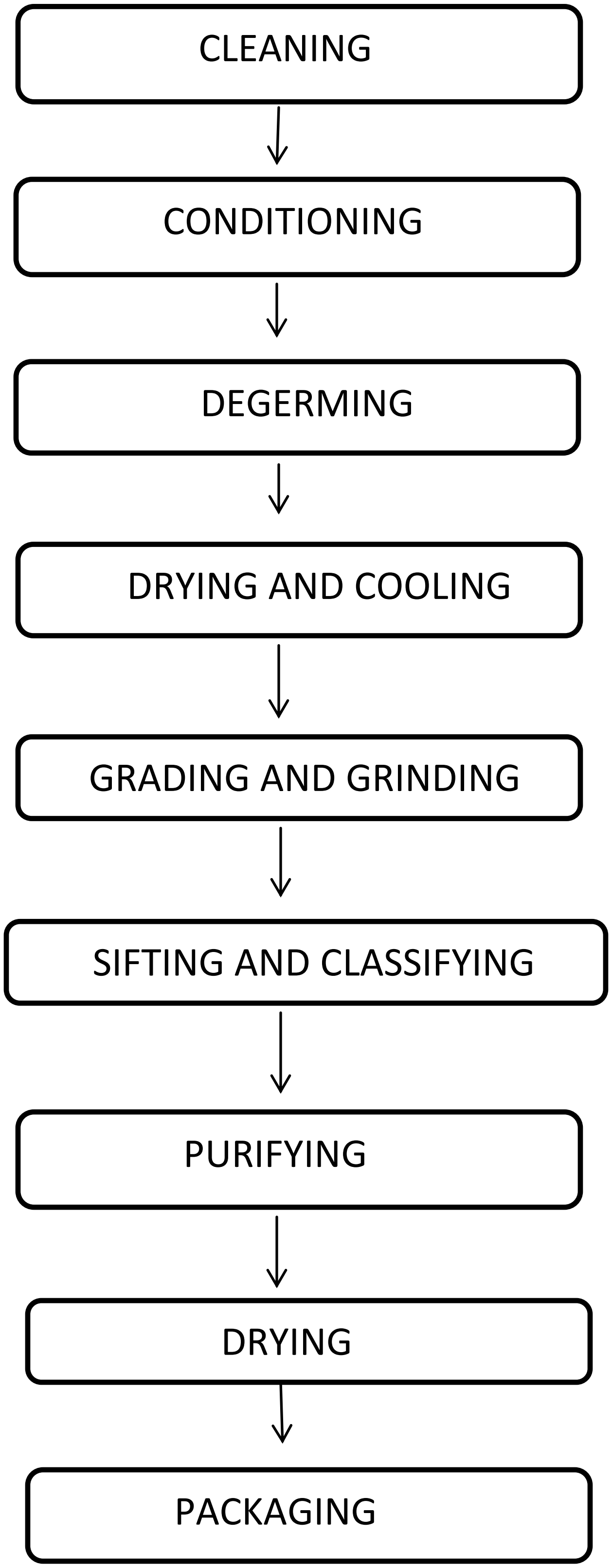

Figure 2.3.1 Commercial production of maize grits

2.4.2 Starch extract

Starch is the source of fermentable sugars and is made up of amylose and amylopectin. Amylose consist of unbranched chains of poly (1- 4)-alpha-D-glucopyranose and amylopectin has same components linked with both branched 1-6 and 1-4 glycosidic linkages (Briggs *et al*; 2002).

2.4.3 Gelatinization temperature

Gelatinisation temperature of starch in white maize ranges from 70 – 75 ºC, (Moll *et al*; (1990). Cereals such as maize and rice are commonly used as adjuncts in brewing (Briggs *et al*; 2002). The gelatinization temperature of the starch in these adjuncts is higher than that used for saccharification in mashing. Therefore it is necessary to cook the adjunct prior to addition to the mash to ensure complete gelatinization and liquefaction (Briggs *et al*; 2002). Adjunct cooking is traditionally carried out using the addition of some malt into the cereal cooker along with the adjunct.

2.4.4 Fat/oil content

High levels of oil in adjuncts are deleterious to beer quality. They contribute to high hazes (Albini et al., 1987) and flavour deterioration, which reduces shelf life in beer.

2.4.5 Protein content

Proteins and peptides have been implicated in contributing to palate fullness and improving head retention, and stabilising foam. Amino acids are used by yeasts cells as food for growth during fermentation. The spectrum of amino acids available to the yeasts plays an important role in determining the volatile constituents of the final beer, for example, large quantities of valine tend to suppress the formation of diacetyl during fermentation yet diacetyl plays a role in enhancing beer flavour (Briggs *et al*, 1981)

2.5 Preparation of maize grits

The yellow maize kernels available were taken for milling to a grinding mill. The kernels were milled abrasively into grits that were decorted. Some of the grits had their germs remaining attached because the mill was not meant for degerming. Since germs contain oil which is undesirable in lager beer production, the grits were separated manually by hands and by winnowing to leave only those that were degermed. The milled grits were pound using pestle and mortar to try and further purify. The grits were taken to the Lagers Plant laboratory (Southerton) where they were further ground to small coarse grits using a lab grinder to try and match the size of the maize grits suppliers, (Fig 2.5.1).

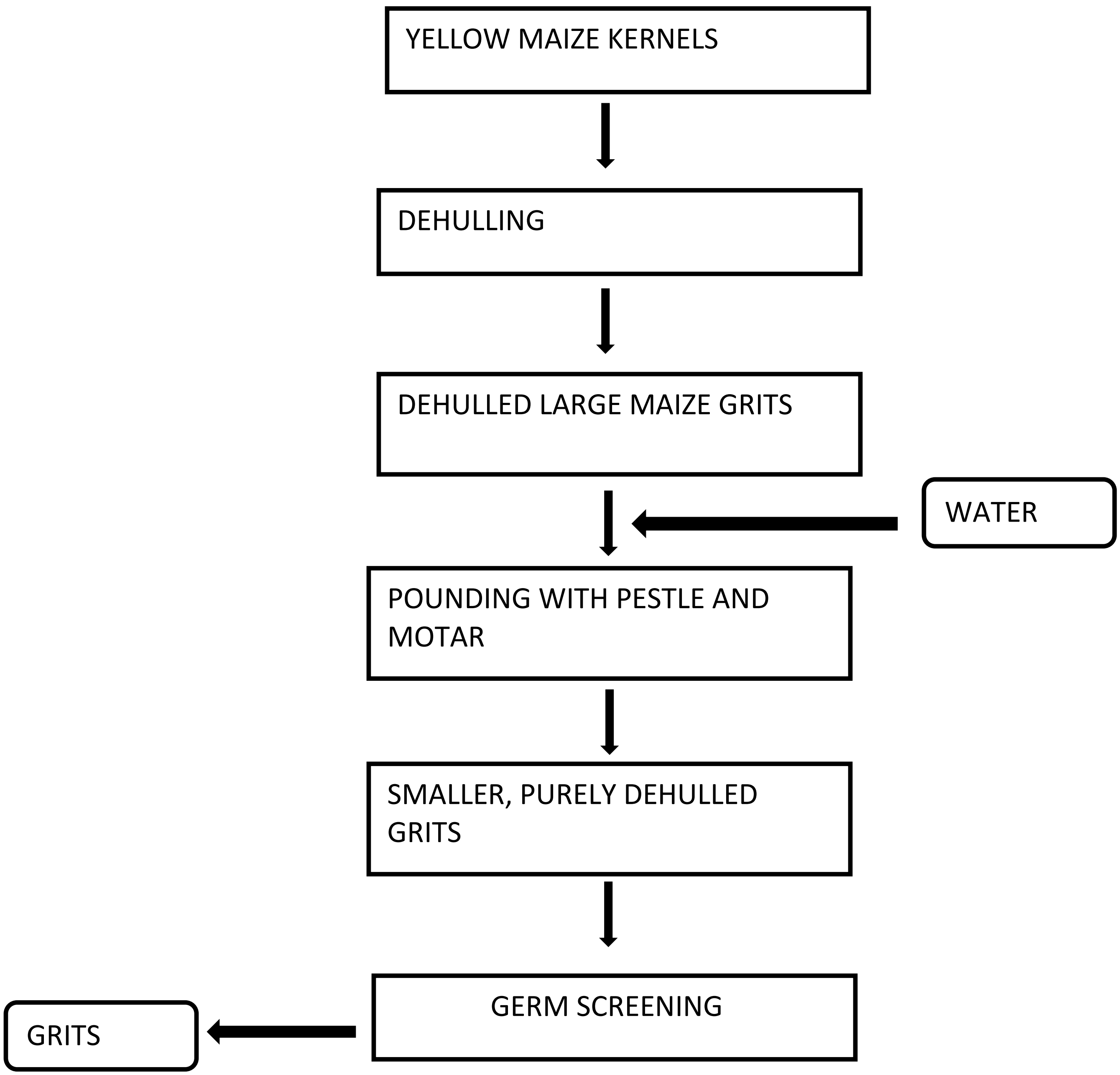

Figure 2.5.1 A flow diagram showing the preparation of maize grits

2.6 Uses of adjuncts in lager beer manufacturing

Adjuncts are mainly used to provide starch extract as a supplement for malted barley. They also contribute little or no polyphenolic substance which enhances the beer flavour (Briggs, *et al*., 1981). The flavour contributions differ with each adjunct, for instance rice has a very neutral aroma and taste while corn tend to impart a fuller flavour to beer. Some adjuncts are used to produce light tasting or light coloured beers that have the alcoholic strength of most beers (Briggs, 1988). Adjuncts results in beers with enhanced physical stability, superior chill proofing qualities and greater brilliancy. The greater physical stability has to do with the fact that adjuncts contribute very little proteinaceous material to wort and beer which is advantageous in terms of colloidal stability (Briggs, *et al*, 2002).

However, during processing a non- gelatinised adjunct needs to be heated in a separate cereal cooker to complete liquefaction since the starch gelatinisation temperature of the adjunct is higher than that used for malt saccharification (starch hydrolysis). The cooked adjunct is then added directly to the malt mash in a mash tun. The malt enzymes from the malt mash are used to hydrolyse the starch from the adjunct converting it to sugars ready for fermentation (Moll *et al*, 1990). The white maize grits are added to malt grist in different proportions depending on the beer brand being brewed, as each brand has its own proportion of adjuncts and the malt. White maize grits have known values of chemical components, and now the project is aimed to compare and contrast their profile with that of red maize after the investigations.

Table 2.6.1 Advantages and disadvantages of using adjuncts

Advantages	Disadvantages
They provide extract at a lower cost than malt	Some require additional processing steps combined with the associated extra hardware, labour and CIP costs
Enhance physical and microbial stability due to decreased protein levels	FAN levels can be critically diluted causing irregular eve stuck fermentations coupled with diacetyl production
Can increase production capacity	Alteration of flavour profiles can be detrimental
Allow product flavour profile modification	There can be difficulty in achieving complete saccharification
Reduced cell wall material can reduce wort viscosity	Extra lauter tun bed loadings coupled with viscous wort can slow run-off
Diminished lipid and fat levels can minimise staling and loss of head retention	Excessive use of fine flours can cause set mashes
Certain adjuncts can improve head retentation	
Reduced protein levels produce less trub and can improve hop utilisation	

The overall brewing value of an adjunct can be assessed with the equation; Brewing Value = (Extract + Contribution to beer quality) – (Brewing Costs).

2.7 Adjunct starch and gelatinization temperature

The chemistry and structure of starch influences the way in which the adjuncts are processed. The granular starch of cereals comprises two glucose polymers which are amylopectin (70-80%) and amylose (20-30%). The most important property of a starch granule is the gelatinisation temperature. This is the temperature at which the starch dextrins are broken down to their individual glucose polymers. Only after thermal gelatinisation will the starch liquefying (α-amylase) and saccharifiying (β-amylase) enzymes operate efficiently.

2.8 Starch Structure Granules have partly amorphous and partly crystalline (structured) sections.

These structures produce a layered composition, which generates the characteristic "Maltese cross" appearance when viewed under the microscope in polarised light. When gelatinisation is complete and the crystalline structure disrupted, the black "Maltese cross" can no longer be observed. This is because the light is no longer polarised.

Typically, mashing systems are not operated at temperatures above 65°C, as the starch degrading enzymes will be denatured and cease to function. This is further complicated by the fact that the more abundant, small B-Type granules possess higher gelatinisation temperatures than the large A-Type granules. As such, adjuncts with gelatinisation temperatures greater than 65°C cannot simply be added to the mash as part of the normal grist bill, otherwise the starch will not degrade. This gives rise to extract loss and potential for carbohydrate haze formation. Additionally, unconverted starch will increase wort viscosity and hinder separation and run-off in the lauter tun. The starch will continue to pass through the brewhouse and generate uncontrollable carbohydrate hazes, affecting beer stability and shelf life. In order to overcome the problem of critical mashing temperatures, supplementary plant hard ware is necessary. This takes the form of cereal cookers; cereal cookers pre-cook/gelatinise starch from adjunct cereals such as maize, rice and sorghum. Further milling equipment, and storage requirements may also be needed, whilst the use of flours and starches may demand installation of specialised pneumatic conveyors. Consequently, extra costs are incurred in the form of further labour, CIP, maintenance expenditure and others.

CHAPTER 3: MATERIALS AND METHODS

The study was conducted at Delta Beverages Lagers Plant in Southerton Harare. Formulations and methodology procedures were adapted from the SAB Brewing Manual which was used at the plant in carrying out analyses of different brewing materials including white maize grits. White maize grits obtained from the plant samples were taken from delivered batches from maize grits suppliers such as National Foods Company.

3.1 General methods of analysis

3.1.2 Preparation of maize grits

The white and yellow maize kernels were milled abrasively into grits that were decorted. Degermed grits were separated from the degermed by winnowing. The milled degermed grits were pounded using pestle and mortar to further purify them. The grits were taken to the laboratory where they were further ground to smaller coarse grits using a lab grinder to match the size of the maize grits suppliers. The steps are summarised in a flow diagram (Fig. 3.1).

3.1.3 Preparation of wort using maize grits and malted barley

3.1.4 Maize cooking

Three samples of each variety were taken each weighing 10 g. Each sample was mixed with 100 ml of distilled water in a 300 ml steel can which was placed on a hot plate for cooking. The mixture was stirred until a thick porridge like slurry was formed. Immediately, the mixture was removed from the hot plate and the contents were poured into a steel container immersed in a mash bath.

3.1.5 Mashing

The cooked maize grits were mixed with 23 g of malt in a mash bath, and mashed for a period of 90 min. The mash was heated in a water bath under controlled temperatures while being stirred. Initially the mixture was heated to 45 ºC and maintained at that level for 30 min. The temperature was raised to 60 ºC and maintained again for 30 min. The mixture was finally heated to 70 ºC also for 30 min to complete the mashing process.

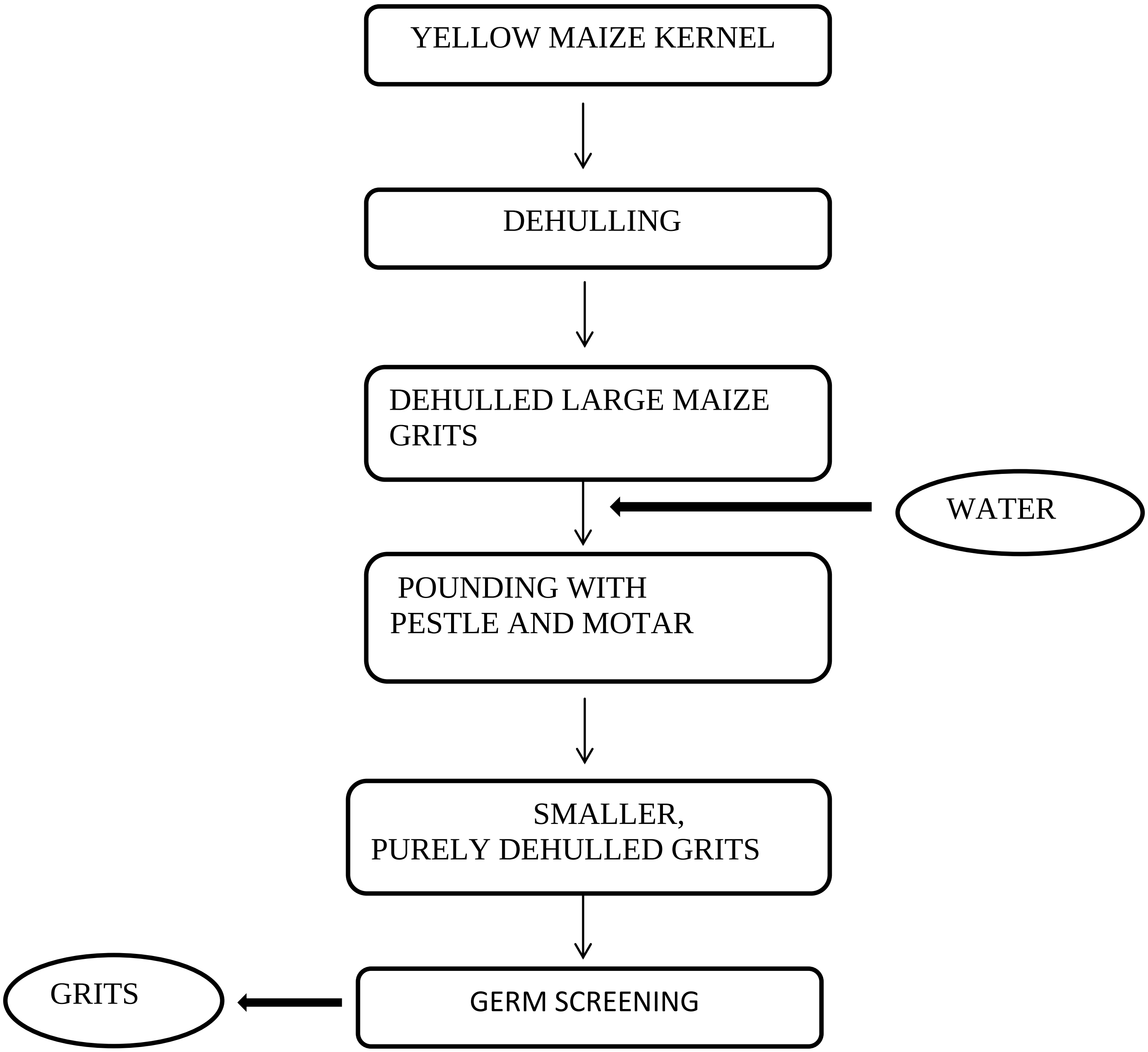

Figure 3.1 A flow diagram for preparation of white and yellow maize grits

3.1.6 Lautering

The mash was removed from the mash bath and filtered through fluted filter paper. The residues were rinsed with four splashes of hot water (70 ºC) using a wash bottle (sparging). The filtrate was poured in a steel can for wort boiling.

3.1.7 Wort boiling and cooling

The filtered wort was heated to boil for an hour and then cooled to about 20 ºC in an ice bath. Wort from the brew house was received at a temperature of about 96 ^{0} C this was cooled rapidly by means of a plate heat exchanger from 96 ºC to 10 ºC. Oxygen was added to the wort as it was a living organism and was required for yeast cell wall formation in the early stages of fermentation as it respires aerobically. The heat exchanger used for cooling had a capacity of 700 hls per hour.

3.2 Characterization of wort

3.2.1 Determination of colour of cooked maize

A total of three samples, each weighing 15 g were collected from each variety of maize grits. Each sample was poured into a 300 ml steel can and mixed with 150 ml of water. The sample was boiled on a hot plate with constant stirring. The grits were cooked for 30 min and then filtered through fluted filter paper. The filtrate collected was attemperated to 20 ºC, and samples were filled into cuvettes and the absorbance of the samples read at 430nm wavelength (EBC, 1975) using the Unicam UV-Visible spectrometer (serial No.UV1 060521). The optical density (OD) was expressed in terms of European Brewing Convention colour units as follows,

Colour units = OD x 25(EBC, 1975).

3.2.2 Starch presence by iodine test

Wort was purified by centrifuging at 2000 G before filtration through fluted filter paper and filter aid. A volume of 10 ml of the purified wort was pipetted into a test tube. Iodine solution was added to the wort in two drops. The solution was mixed and observed for any colour changes.

3.2.3 Wort gravity

The prepared wort samples were tested for the gravity (which is the strength of the sugars present in the wort) by dipping the saccharometer in the sample which detected the gravity level. Gravity gave the present extract when evaluated against °Plato.

3.3 Proximate analysis of grits

3.3.1 Moisture content determination

A total of three samples of 5 g each of maize grits were measured from the main batches of yellow and white maize grits available. Each sample was dried in an oven thermostatically controlled at 105 °C for 3 h. The dish was removed and placed in a desiccator for 30 min to cool and reweighed on an analytical balance. Each set (three samples white grits and three samples yellow grits) were dried to a constant mass. The moisture content was calculated as follows:

Mass of water = initial mass of grain- final mass of grain after drying

Mass of dry matter = final grain mass reached after drying

% moisture content on dry basis = (mass of water/ mass of dry matter) x 100.

3.3.2 Gelatinization temperature determination

Samples of yellow and white maize grits were weighed. Each sample of 10 g was mixed with 100 ml of distilled water and heated on a hot plate in a steel can. The mash was cooked whilst paying particular attention on the temperature. The moment the mash formed thick slurry, the temperature was recorded as the gelatinization temperature of the maize grits.

3.3.3 Determination of starch extract

Samples from gelatinized mash of grits were taken, filtered through fluted filter paper and poured in 20 ml plastic vials which were mounted onto a beer analyser where the starch extract was read.

3.3.4 Protein content determination by Kjeldahl method

Protein content analysis was done using three samples of maize grits for each variety. A mass of 10 g of maize grits was weighed on an analytical balance. Each sample in 40 ml of sulphuric acid was heated in a fume cupboard. A volume of 5 ml potassium sulphate was added which increased the boiling point of the medium (from 169 ºC to 189 ºC). The mixture was left to boil until a colourless solution was obtained after boiling the solution was neutralised with sodium hydroxide, afterwards sulphuric acid was added and then back titrated with sodium hydroxide using Tashiro indicator. The amount of ammonia present in the sample is thus the amount of nitrogen present which represents the amount of crude protein.

3.3.5 Fat determination by soxhlet extraction

Firstly all the glassware to be used was rinsed with petroleum ether, drained, and dried in an oven at 102 ºC for 30 min and cooled in desiccators. A piece of cotton wool was placed in the bottom of a 100 ml beaker. A plug of cotton wool was also placed in the bottom of the extraction thimble which was put in the beaker. A mass of 5 g maize grits was weighed into the thimble after which a cotton wool was placed on the top of the thimble. The sample was dried in an oven at 102 ºC for 5 hours after which it was allowed to cool in a desiccator (SABMiller manual, 2000). The thimble was inserted in a soxhlet solid extractor. A clean, dry 150 ml round bottomed flask. Ninety ml of petroleum spirit was placed in a pre-weighed flask. The extraction unit was assembled over a heating mantle and the solvent in the flask was heated to boiling. Heat was adjusted so that the solvent dripped from the condenser into the sample chamber at the rate of about six drops per second and the extraction process was continued for 6 h. The solvent was removed by heating on mantle and dried to constant weight in an oven at 102 ºC. The flask was finally cooled in a desiccator and weighed on an analytical balance. The fat content was calculated using the weight of the empty flask and the weight of the flask with the contents.

3.3.6 Limit of extract

The wort was filtered using fluted filter paper and filter aid into 500 ml plastic containers. A mass of 30 g fresh yeast was introduced into the wort which was closed by perforated rubber cocks. The plastic bottle was shaken to dissolve the yeast and then placed into an incubator which a shaker inside. The temperature was set at 20 ºC and the bottles were left to ferment for 24 h. The fermented wort was taken, filtered and poured into a plastic vial which was mounted on a beer analyser to read the limit of extract result.

3.3.7 Wort fermentation

A one litre sample of wort from wort boiling and cooling process was taken for fermentation in micro-fermentors. A volume of 600 ml wort was piped into a steel micro-ferment vessel. A mass of 20 g yeast were pitched into the vessel at 16 ºC and oxygen was pumped at 16 to 20 ppm (parts per million). The wort was left to ferment for 14 days. The beer was collected, filtered and analysed for alcohol content.

3.4 Data analysis

Two-sample T-test (Unpaired T-test) and 95% confidence intervals were used to compare protein content, fat content, moisture content, gelatinisation temperature, colour of cooked maize, limit of extract, starch extract, presence of starch, fermentability-alcohol content and wort gravity of white maize and yellow maize as adjuncts

CHAPTER 4: RESULTS

4.1 Characterization of wort

A higher colour index was obtained for yellow maize (0.36) than in white maize (0.00). The cooked yellow maize grits filtrate had a yellow blemish with an absorbance between 0.35 nm and 0.4 nm at a wavelength of 430 nm, which was much higher than that of white maize (between 0.3 nm and 0.32 nm). Wort samples from yellow maize had some starch residues present, whereas there was no starch recorded in white maize samples. Wort gravity results observed of yellow maize grits were (15.72^{o} Plato ± 0.21) compared to those of white maize grits (15^{o} Plato ± 0.15) which were slightly lower (Table 1).

4.2 Proximate analysis of grits

The white maize grits had higher moisture content of 12.27% compared to that of yellow maize grits which was 12.3%. Yellow maize grits had higher gelatinization temperature (78 ^{o}C ± 5) compared to that of white maize grits (76.7^{o}C ± 2.08) (Table 1). Yellow maize grits had a higher starch extract with a mean and standard deviation of 93% ± 2 compared to that of white maize grits (89.8% ± 3.0) (Table 1). The protein content of yellow maize grits were higher compared to those of white maize grits (Table 1). Yellow maize grits had a higher fat content with a mean of 0.85 % than white maize grits with 0.52% (Table 1).The limit of extract of wort from yellow maize grits (1.77%) was higher than that of white maize grits (1.52% (Table 1). Alcohol content recorded for yellow maize grits (6.80 %) was higher compared to that of white maize grits (6.64%), (Table 1). The levels of fermentable-alcohol content obtained were between 6.6 and 6.9%.

Table 4.1 Comparative proximate analyses of white maize grits and yellow maize grits

PARAMETERS	WHITE MAIZE GRITS (Mean ± SD)	YELLOW MAIZE GRITS (Mean ± SD)
Protein content (%)	8.46 ± 0.15	9.12 ± 0.38
Gelatinization temperature (^{O}C)	76.7 ± 2.08	78 ± 5
Starch extract (%)	89.8% ± 3.01	93 ± 2
Moisture content (%)	12.27 ± 0.49	12.3 ± 0.85
Fat content (%)	0.52 ± 0.03	0.85 ± 0.27
Limit of extract (%)	1.52 ± 0.03	1.77 ± 0.30
Wort gravity (^{O}Plato)	15.65 ± 0.15	15.72 ± 0.21
Fermentability-alcohol content (%)	6.64% ± 0.008	6.80 ± 0.17

CHAPTER 5: DISCUSSION

5.1 General discussion

5.1.1 Characterization of wort

5.1.2 Colour of cooked maize

One of the objectives of this study was to evaluate and compare the characteristics of wort produced from yellow and white maize. Yellow maize had higher colour of cooked maize than white maize. This high colour index poses problems to the brewer as the colour of beer has to be adjusted to suit consumer preferences. Other adjuncts such as cassava pose the same problem as yellow maize in that they produce high colour of wort (Briggs, 1998). Lager beers are should have colours in the range 6-12 nm (SABMiller manual, 2000) although each brand can have its own colour that gives it the consumer brand identity (SABMiller manual, 2000). So if the colour of that brand changes due to use of yellow maize grits, the consumers might not accept the change. The specifications (SABMiller manual, 2000) that are being used currently are applicable when white maize grits are used because they do not contribute any colour to the wort or beer, but are added with caramel which gives beer its colour as per its specifications. Caramel is a cost that can be avoided by the use of yellow maize (Kunze, 1995). However, some brands like Lion lager are darker and caramel is used to darken the colour, and also Castle Milk Stout lager is prepared with roasted malt to enhance its colour (Kunze, 1995) and flavour which gives it a distinctive identity.

5.1.3 Starch presence

Another objective of this study was to evaluate and compare the characteristics of wort produced from yellow and white maize. The study showed that there were starch residues on yellow maize, while white maize had none. The starch residue recorded for in yellow maize suggests incomplete conversion of starch in the mash tun, which leads to extract losses, filtration problems and beers with high hazes as well as poor shelf life (SABMiller manual, 2000). In addition, presence of starch residues is associated with presence of non-fermentable sugars. Undegraded starch in wort cannot be fermented by yeast and hence cannot be converted to alcohol. Presence of starch was also noted in rice and sorghum adjuncts (Kunze, 1995).

5.1.4 Wort gravity

This study sought to evaluate and compare the characteristics of wort produced from yellow and white maize. Yellow maize had higher values of wort gravity than white maize. The high wort gravity recorded for yellow maize indicates that there was maximum extraction of fermentable and non-fermentable sugars such as glucose, fructose, maltose, maltotriose and dextrins in the mashing process (SABMiller manual, 2000). The high wort gravity (15.72^{o} Plato) was still within acceptable range of 15 ^{o}Plato (Briggs *et al*, 2000). Yellow maize wort gravity reduces the quantity of raw material used such as the maize grits and yeast in the mashing, fermentation and filtration processes.

5.2 Proximate analysis of grits

5.2.1 Moisture content

Another objective of this study was to perform and compare the proximate analysis of yellow and white maize. Although the moisture content of yellow maize grits was higher than that of white maize grits was within an acceptable range of 12-15% (Brooker *et al.*, 1987).

5.2.2 Starch extract

Yellow maize grits contained higher levels of starch extract than white maize grits recorded. Yellow maize grits had higher starch extract (93%) than the 79-90% recorded by Briggs *et al*. (2002). However; the high starch extract in yellow maize is acceptable in lager beer brewing (SAB Brewing Manual 2000). The high starch extracts in yellow maize indicates high levels of fermentable sugars in the maize kernels; as a result more sugars are obtained resulting in high fermentability of alcohol, give more beer on dilution (Brooker *et al*., 1987).

5.2.3 Protein content

Yellow maize had higher protein content (9.12%) than white maize (8.46%). Protein content may depend on factors like the type of soil on which the maize was grown. Yellow maize might have received enough nutrients (from the soil) needed for growth as a plant than white maize. Other factors like the genetic makeup may also result in such differences in the amount of protein between yellow and white maize. Researches carried out on other adjuncts such as sorghum had high alcohol content (9.2%) and cassava (8.9%) and they have the same effect on beer production as yellow maize.

The high protein content provides abundance of amino acids, which are needed by yeast (yeast food) for growth. However, high amounts of protein in the grits can have negative effects on beer quality (Briggs, 2002). Some products of proteolysis like nitrogenous compounds produced during mashing may cause formation of haze in beer. Protein content of both varieties was within the literature ranges (8-9%), (Briggs, 2002).

5.2.4 Fat content

Yellow maize grits had a fat content of 0.85%, which was higher than that of white maize. Fat content recorded in in yellow maize grits was higher than that recorded previously (0.5%,Moll *et al*, 1990). Other adjuncts have fat content within the literature range, for example, cassava had 0.56% while rice had 0.5% making them better adjuncts than yellow maize

Too much fat in grits is undesirable results in rancid beer due to oxidation. Moreover, high fat content leads to beer haze and production of undesirable flavours that shorten the shelf life of the beer (Briggs, 2002).

5.2.5 Limit of extract

The study showed higher limit of extract of yellow maize (1.77%) compared to that of white maize (1.52%). The limit of extract was comparable to that of cassava (1.6%, Brooker *et al*., 1987), which is used as an adjunct in lager beer brewing.

5.2.6 Fermentable alcohol content

The higher fermentable alcohol content of yellow maize (6.8%) as compare to that of white maize was perhaps a result of the type of yeast used which favoured yellow maize (Brooker *et al*., 1987). Using castle lager as an example, this has to be diluted to 5% alcohol content; more volume of beer is obtained. Alcohol content of yellow maize was slightly higher than that of sorghum (6.6%, Briggs *et al*., 2002). Yellow maize produced higher fermentable alcohol than other adjuncts such as white maize and sorghum (Brooker *et al*., 1987).

5.3 RECOMMENDATIONS

The proximate composition of yellow maize grits including starch extract, protein content, and moisture content were within acceptable ranges, which makes it a suitable substitute for white maize as an adjunct in lager beer brewing despite its high fat content and gelatinization temperatures as these can be managed during processing. Yellow maize wort had high colour of cooked maize grits but it can be managed during production. Yellow maize grits can be successfully used in lager beer manufacturing to produce high gravity wort and expected levels of alcohol. Yellow maize adjunct substitute for white maize may be used in overcoming production challenges such as wort generation, fermentability, and final product quality assessed.

5.4 CONCLUSION

Wort gravity) and colour of cooked maize grits of yellow maize were higher compared to those of the grits of white maize. Yellow maize grits had a higher starch, content than white maize making it a better alternative since wort of a higher sugar content produces beer with a higher alcohol percentage. Protein content and moisture content of yellow maize (9% and 12%, respectively) were similar to those of white maize (8.46%, and 12.27%, respectively) and they were within acceptable ranges for lager beer manufacturing. Undesirable properties of yellow maize grits including high fat content, colour and gelatinization temperatures were recorded but they are insignificant since they can be managed during the brewing process. From the wort and proximate analysis done, yellow maize can substitute for white maize in lager beer brewing.

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APPENDICES

APPENDIX 1

Moisture content

Sample	White Maize Grits	Yellow Maize Grits
1	12.6	13.1
2	11.7	12.4
3	12.5	11.4
Mean	12.27	12.3
Standard Deviation	0.49	0.85

T-Test

Group Statistics

	Treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	12.267	.4933	.2848
	2	3	12.300	.8544	.4933

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	.676	.457	-.059	4
	Equal variances not assumed			-.059	3.200

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.956	-.0333	.5696	-1.6148
	Equal variances not assumed	.957	-.0333	.5696	-1.7836

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	1.5481
	Equal variances not assumed	1.7170

APPENDIX 2

Gelatinization temperature

Sample	White Maize Grits	Yellow Maize Grits
1	75	73
2	76	78
3	79	83
Mean	76.7	78
Standard Deviation	2.08	5

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	76.67	2.082	1.202
	2	3	78.00	5.000	2.887

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	1.049	.364	-.426	4
	Equal variances not assumed			-.426	2.673

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.692	-1.333	3.127	-10.015
	Equal variances not assumed	.702	-1.333	3.127	-12.010

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	7.348
	Equal variances not assumed	9.343

APPENDIX 3

Starch extract

Sample	White Maize Grits	Yellow Maize Grits
1	87	91
2	89.5	93
3	93	95
Mean	89.8	93
Standard Deviation	3.01	2

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	89.833	3.0139	1.7401
	2	3	93.000	2.0000	1.1547

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	.486	.524	-1.516	4
	Equal variances not assumed			-1.516	3.475

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.204	-3.1667	2.0883	-8.9648
	Equal variances not assumed	.214	-3.1667	2.0883	-9.3269

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	2.6315
	Equal variances not assumed	2.9935

APPENDIX 4

Protein content

Sample	**White Maize Grits %**	**Yellow Maize Grits %**
1	8.48	9.45
2	8.30	9.20
3	8.60	8.70
Mean	8.46	9.12
Standard Deviation	0.15	0.38

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	8.4600	.15100	.08718
	2	3	9.1167	.38188	.22048

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	2.452	.192	-2.770	4
	Equal variances not assumed			-2.770	2.610

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.050	-.65667	.23709	-1.31493
	Equal variances not assumed	.081	-.65667	.23709	-1.47906

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	.00160
	Equal variances not assumed	.16573

APPENDIX 5

Fat content

Sample	**White Maize Grits %**	**Yellow Maize Grits %**
1	0.50	0.70
2	0.55	0.70
3	0.50	1.16
Mean	0.52	0.85
Standard Deviation	0.03	0.27

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	.5167	.02887	.01667
	2	3	.8533	.26558	.15333

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	12.562	.024	-2.183	4
	Equal variances not assumed			-2.183	2.047

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.094	-.33667	.15424	-.76490
	Equal variances not assumed	.158	-.33667	.15424	-.98583

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	.09156
	Equal variances not assumed	.31250

APPENDIX 6
Limit of extract

Sample	White Maize Grits %	Yellow Maize Grits %
1	1.49	1.50
2	1.52	1.72
3	1.55	2.10
Mean	1.52	1.77
Standard Deviation	0.03	0.30

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	1.5200	.03000	.01732
	2	3	1.7733	.30353	.17525

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	5.511	.079	-1.439	4
	Equal variances not assumed			-1.439	2.039

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.224	-.25333	.17610	-.74226
	Equal variances not assumed	.285	-.25333	.17610	-.99729

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	.23560
	Equal variances not assumed	.49062

APPENDIX 7

Wort gravity

Sample	White Maize Grits	Yellow Maize Grits
1	15.49	15.49
2	15.68	15.78
3	15.78	15.89
Mean	15.65	15.72
Standard Deviation	0.15	0.21

T-Test

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	15.6500	.14731	.08505
	2	3	15.7200	.20664	.11930

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	.541	.503	-.478	4
	Equal variances not assumed			-.478	3.616

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.658	-.07000	.14652	-.47679
	Equal variances not assumed	.660	-.07000	.14652	-.49443

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	.33679
	Equal variances not assumed	.35443

APPENDIX 8

Fermentability-alcohol content

Sample	**White Maize Grits %**	**Yellow Maize Grits %**
1	6.55	6.65
2	6.67	6.78
3	6.70	6.98
Mean	6.64	6.80
Standard Deviation	0.008	0.17

Group Statistics

	treatment	N	Mean	Std. Deviation	Std. Error Mean
Data	1	3	6.6400	.07937	.04583
	2	3	6.8033	.16623	.09597

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Data	Equal variances assumed	1.296	.318	-1.536	4
	Equal variances not assumed			-1.536	2.867

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference
					Lower
Data	Equal variances assumed	.199	-.16333	.10635	-.45862
	Equal variances not assumed	.226	-.16333	.10635	-.51087

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
Data	Equal variances assumed	.13195
	Equal variances not assumed	.18420

APPENDIX 9
Colour of cooked white and yellow maize grits

Sample	White Maize Grits	Yellow Maize Grits
1	0.00	0.36
2	0.00	0.36
3	0.00	0.36

APPENDIX 10

Presence of starch

Wort Sample (Yellow grits and malt)	Presence of starch
1	Negative
2	Positive
3	Positive
Wort Sample (White grits and malt)	
1	Negative
2	Negative
3	Negative

APPENDIX 11
95% CI

Case Processing Summary

	parameter	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
value	moisture content	6	100.0%	0	0.0%	6	100.0%
	gelatinisation temperature	6	100.0%	0	0.0%	6	100.0%
	starch extract	6	100.0%	0	0.0%	6	100.0%
	protein content	6	100.0%	0	0.0%	6	100.0%
	fat content	6	100.0%	0	0.0%	6	100.0%
	limit of extract	6	100.0%	0	0.0%	6	100.0%
	wort gravity	6	100.0%	0	0.0%	6	100.0%
	fermentability-alcohol content	6	100.0%	0	0.0%	6	100.0%

Descriptives

	Parameter			Statistic	Std. Error
value	moisture content	Mean		12.2833	.25484
		95% Confidence Interval for Mean	Lower Bound	11.6282	
			Upper Bound	12.9384	
		5% Trimmed Mean		12.2870	
		Median		12.4500	
		Variance		.390	
		Std. Deviation		.62423	
		Minimum		11.40	
		Maximum		13.10	
		Range		1.70	
		Interquartile Range		1.10	
		Skewness		-.369	.845
		Kurtosis		-.801	1.741
	gelatinisation temperature	Mean		77.3333	1.42984
		95% Confidence Interval for Mean	Lower Bound	73.6578	
			Upper Bound	81.0089	
		5% Trimmed Mean		77.2593	
		Median		77.0000	
		Variance		12.267	
		Std. Deviation		3.50238	
		Minimum		73.00	
		Maximum		83.00	
		Range		10.00	
		Interquartile Range		5.50	
		Skewness		.632	.845
		Kurtosis		.377	1.741
	starch extract	Mean		91.4167	1.17201
		95% Confidence Interval for Mean	Lower Bound	88.4039	
			Upper Bound	94.4294	
		5% Trimmed Mean		91.4630	
		Median		92.0000	
		Variance		8.242	
		Std. Deviation		2.87083	
		Minimum		87.00	

	Maximum		95.00	
	Range		8.00	
	Interquartile Range		4.63	
	Skewness		-.499	.845
	Kurtosis		-.361	1.741
protein content	Mean		8.7883	.18112
	95% Confidence Interval for Mean	Lower Bound	8.3228	
		Upper Bound	9.2539	
	5% Trimmed Mean		8.7787	
	Median		8.6500	
	Variance		.197	
	Std. Deviation		.44364	
	Minimum		8.30	
	Maximum		9.45	
	Range		1.15	
	Interquartile Range		.83	
	Skewness		.709	.845
	Kurtosis		-1.053	1.741
fat content	Mean		.6850	.10210
	95% Confidence Interval for Mean	Lower Bound	.4225	
		Upper Bound	.9475	
	5% Trimmed Mean		.6689	
	Median		.6250	
	Variance		.063	
	Std. Deviation		.25010	
	Minimum		.50	
	Maximum		1.16	
	Range		.66	
	Interquartile Range		.32	
	Skewness		1.765	.845
	Kurtosis		3.336	1.741
limit of extract	Mean		1.6467	.09701
	95% Confidence Interval for Mean	Lower Bound	1.3973	
		Upper Bound	1.8960	
	5% Trimmed Mean		1.6302	

	Median		1.5350	
	Variance		.056	
	Std. Deviation		.23763	
	Minimum		1.49	
	Maximum		2.10	
	Range		.61	
	Interquartile Range		.32	
	Skewness		1.870	.845
	Kurtosis		3.338	1.741
wort gravity	Mean		15.6850	.06737
	95% Confidence Interval for Mean	Lower Bound	15.5118	
		Upper Bound	15.8582	
	5% Trimmed Mean		15.6844	
	Median		15.7300	
	Variance		.027	
	Std. Deviation		.16502	
	Minimum		15.49	
	Maximum		15.89	
	Range		.40	
	Interquartile Range		.32	
	Skewness		-.300	.845
	Kurtosis		-1.699	1.741
fermentability-alcohol content	Mean		6.7217	.05997
	95% Confidence Interval for Mean	Lower Bound	6.5675	
		Upper Bound	6.8758	
	5% Trimmed Mean		6.7169	
	Median		6.6850	
	Variance		.022	
	Std. Deviation		.14689	
	Minimum		6.55	
	Maximum		6.98	
	Range		.43	
	Interquartile Range		.21	
	Skewness		1.123	.845
	Kurtosis		1.820	1.741