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Full Length Research Paper

Physico-chemical assessment of sorghum brew adjunct and barley brew lager beer

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The type of alcoholic beverage produced in any particular region or country almost entirely reflects the types of crop grown. Thus the cooler region of Europe, Scandinavia, Poland and Russia produces beer and lagers from barley (Palmer, 1992). In tropical Africa, alcoholic beverages especially beer have been brewed from micro-organisms especially fungi are to expect. It is necessary to treat harvested crop with fungicide to prevent spoilage (Gomez, 1992). Sorghum has a wide range of colors and sizes. The best known are the white (*farafara),* yellow (*kaura)* brown and the red types (Gomez, 1992). Although the red types are malted for traditional beer production, the white type is preferred for modern beer production (Palmer, 1992). The type and strain of yeast used in fermentation has a great influence on the taste and character of beer produced (Kunze, 1996). Apart from brewing, sorghum has been used extensively in food industries. Vitamin enriched sorghum based product are enjoying acceptance at institutional levels as mid shift drinks and high energy breakfast food (Aluko, 1989). Sorghum is also used in industrial production of cellulose, paper, starch, sugar and chemicals (Subramaniann et al., 1989). Other uses of sorghum include livestock feed production (Al- Hazzan et al., 1989). Sorghum as adjunct in beer production already has a widespread acceptance. However, the availability of the grain poses a great problem to the brewing industry. Sorghum is already a staple diet, so to make a substantial replacement for barley malt, huge quantities of adjunct will be required (Nweke, 1989).

Key words: Sorghum, beer, adjunct.

INTRODUCTION AND LITERATURE REVIEW

Alcoholic beverages which occur throughout the world in many forms and taste results from the action of microorganisms or enzymes on a wide range of agricultural products such as grapes, grains, and soybeans (Smith, 1996; Rose, 1989). Such biological action was associated with biochemical changes that gave rise to significant organoleptic improvements to the final products (Brill, 1981). These products which are more nutritious and more easily digestible are toxicologically and microbiologically safer (Smith, 1996).The process of fermenting raw materials is of wide diversity, using technology from the most primitive to the most advanced, achieving an outstanding range of sensory and textural quality in the final product (Rose, 1989). Alcoholic beverages and potable spirit industries represent one of the most economically stable sectors in the present day commerce. Materials for alcoholic beverages normally comprise either sugary material (fruit juice, plant sap) or starchy materials (grains or roots) which need to be hydrolyzed to simple sugar before fermentation. When these substrates are incubated with suitable microorganism and allowed to ferment, the end product is a liquid containing from a few percentages to about 16% alcohol with a slightly acidic pH.

The type of alcoholic beverage produced in any particular region or country almost entirely reflects the types of crop grown. Thus the cooler region of Europe, Scandinavia, Poland and Russia produces beer and lagers from barley (Palmer, 1992). In tropical Africa, alcoholic beverages especially beer have been brewed for generations with locally available cereals like sorghum, rice, maize and millet (Okafor, 1987).

Barley malt is also known to be rich in protein and

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enzymes. It has a high ß- glucan and pentosan level when compared to local grains. The enzyme potential of barley malt is sufficient to catabolize additional starch (Kunze, 1996). Consequently, throughout the world, part of the malt, usually 15 to 20% is replaced by unmalted cereal. The unmalted cereal called adjunct was added to remove excess protein which could cause haziness in beer (Kunze, 1996).

Barley malt, whose diastatic power is higher than other cereals, has a high level of maltose producing ß-amylase which is the key enzyme in breaking down malt starch (Palmer, 1996). Due to economic reasons, cheap raw materials are used as adjunct as partial replacement for malt in wort production (Canales, 1979). In some African countries and in some parts of U.S.A, sorghum has been the grain of choice as adjunct in lager beer production, because is cheaper than barley (Okolo et al., 1995).

Sorghum is the fifth largest cereal produced in the world (KUnze, 1996). It is drought resistant and indigenous to Africa. It is a staple food rating third behind rice and wheat (Okolo et al., 1995). It belongs to the grass family, essentially adapted to the semi-arid regions of the world, where it is traditionally used as food, beverages and building materials (Gomez, 1992). Sorghum known as *Sorghum vulgaris* is an old crop with yet unknown genetic variability (Palmer, 1992). It is a dry land summer cereal cultivated in areas of rainfall of 400 and 750 mm and a temperature of 38 to 40°C (House, 1993). During germination, sorghum produced an enzyme, which breaks down the storage materials it contains. Since planting is during the raining season, contamination by microorganisms especially fungi are to be expected. It is necessary to treat harvested crop with fungicide to prevent spoilage (Gomez, 1992). Sorghum has a wide range of colors and sizes. The best known are the white (*farafara),* yellow (*kaura)* brown and the red types (Gomez, 1992). Although the red types are malted for traditional beer production, the white type is preferred for modern beer production (Palmer, 1992).

The type and strain of yeast used in fermentation has a great influence on the taste and character of beer produced (Kunze, 1996). Apart from brewing, sorghum has been used extensively in food industries. Vitamin enriched sorghum based product are enjoying acceptance at institutional levels as mid shift drinks and high energy breakfast food (Aluko, 1989). Sorghum is also used in industrial production of cellulose, paper, starch, sugar and chemicals (Subramanian et al., 1989). Other uses of sorghum include livestock feed, production (Al-Hazzan et al., 1989). Sorghum as adjunct in beer production already has a widespread acceptance. However, the availability of the grain poses a great problem to the brewing industry. Sorghum is already a staple diet, so to make a substantial replacement for barley malt, huge quantities of adjunct will be required (Nweke, 1989).

In brewing the basic principles remain the same over the centuries. This includes malting, mashing, boiling and fermentation (Kunze, 1996). During malting, the grains are allowed to steep in water for 48 to 72 h at 10 to 15°C. The grains are allowed to germinate. However, as soon as the enzymes are produced and before the young seedling can make an appreciable in road into the nutrient reserve of the grain, development of the seedling is halted by drying at a temperature which will not completely inactivate the enzymes.

These enzymes are reactivated during mashing to hydrolyze starch and protein and release nutrients for the nourishment of the yeast during fermentation (Okafor, 1987). After malting the grains are milled and mixed with water. The mash after several processes of brewing is filtered and boiled before fermentation. Wort is usually inoculated with the fermenting organism, yeast. The sugar in the wort is fermented by yeast to alcohol. For this purpose yeast specie such as *Saccharomyces carlsbergensis* are used. Selected strains are systematically isolated and grown (Pollock, 1981).

Yeast has a high vitamin and enzyme content. They are particularly rich in vitamins B_1 and B_6 (Smith, 1996). Yeast makes use of carbohydrates in two ways: by respiration and fermentation. During fermentation, the nitrogen content of the wort, formed as a result of protein hydrolysis should at least be 23 mg of free amino nitrogen to allow for proper yeast nutrition (Malomo, 1993). Yeast cells are usually ovoid or round in shape. They are non-motile cells measuring between 5×10^6 (5 nm) to 10×10^6 (10 nm) in diameter. They reproduced by budding and grow rapidly on a defined medium. They also have a well-developed genetic cycle (Pollock, 1981). Yeast cells are able to ferment the trisaccharide raffinose, made up of glucose, fructose, and galactose. When using an adjunct as a replacement for malt during brewing, it must be remembered that protein is deposited in the adjunct in a more stable form. The protein is degraded only to a slight extent, because of this adjunct mashes contain less molecular weight nitrogenous materials (alpha amino nitrogen) than malt mashes. Adjunct beer therefore always contains more polyphenols. It follows then that the higher the adjunct the less the nitrogenous compounds (Kunze, 1996).

MATERIALS AND METHODS

Raw materials used for brewing were collected from the warehouse of the International Breweries PLC Ilesa. Barley malt (*Hordeum distichon*) or (*Hordeum vulgare*) was the chief raw material used. Others include, raw sorghum (*S. vulgaris*) was used as adjunct, brewing water, yeast (*S. carlsbergensis*), hop, and other additives like Vitamin C (ascorbic acid), sulphuric acid, sodium hydroxide and calcium chloride. These additives are used to adjust the pH of wort, when and where necessary.

Sample collection

Pilsener barley malt (*H. disichon*) with moisture content of 4.55%, kernel weight of 330.4 g was used as the substrate in brewing. The

barley was collected from the warehouse of Intrnational Breweries PLC, Ilesa. The yellow type raw sorghum (*S. vulgare*) with a moisture content of 6.15% and kernel weight of 350.5 g was used as adjunct. This was purchased from L.O. Omole and Sons store, Ilesa.

Brewing process

A laboratory manual Glasbaserei milling machine was used to reduce the particle sizes of the grains and also to expose the starch in the grains in readiness for enzymatic action during brewing. In 100% barley malt brew, 600 g of malted barley was weighed into a flask. In the case of other formulations, the following proportions were used; 90% barley: 10% sorghum = 540 g barley: 60 g sorghum. 80% barley: 20% sorghum = 480 g barley: 120 g sorghum. 70% barley: 30% sorghum = 420 g barley: 180 g sorghum. 60% barley: 40% sorghum = 360 g barley: 240 g sorghum.

Two 25 L capacity Carlsberg's flasks were used for fermentation. An electronic Julabo water bath was used to monitor the temperature of wort during brewing.

Procedure

Six hundred grams of malted barley was weighed and mashed with 1.5 L of water inside a 5.0 L conical flask. This mash was placed inside a water bath and the temperature was raised to between 50 and 55°C for about 20 min, to allow for optimum activity of the enzymes present in the malt. The temperature was later raised to 72°C for 45 min to terminate enzymatic activities. The mash was then allowed to rest for 45 min to allow the mash to undergo complete saccharification (Okafor, 1987).

Saccharification, which is the complete hydrolysis of starch to simple sugar is shown by a brown or colorless reaction with 2% iodine solutions (Brauhaase, 2000). After saccharification, the mash was filtered. The aqueous solution collected, that is, wort was boiled for 1 h. After boiling, the wort was allowed to cool and the following parameters were determined; pH, color, gravity and temperature. The cooled wort was transferred into the Carlsbergen's vessel and inoculated with the fermenting organism. The pitching wort was then kept in the refrigerating incubator at 6°C. With malt/ adjunct brew the gelatinized sorghum adjunct was added to the malt mash at 55°C. The enzyme in the barley malt also acted on the adjunct mash to hydrolyzed the gelatinized starch in the adjunct.

Fermenting organism

A genetically modified strain of *S. carlsbergensis* no. 01185, strain 370 from Horlunann, Hamburg, was used as the fermenting organism. The yeast used was obtained by the propagation of pure yeast culture in the Laboratory.

Yeast propagation

About 5 ml of sterile wort was poured into a test-tube, a loopful of yeast from PDA agar slant was used to inoculate the sterile wort and shaken vigorously. The test-tube was allowed to stand for 24 h. The inoculated wort was transferred into a 100 ml flask containing sterile wort and this was also allowed to stand for another 24 h. This was also transferred into another flask containing 250 ml of sterile wort and subsequently to 500 and 1000 ml sterile wort and each was allowed to stand for 24 h. At the end 1000 ml of fermenting wort was obtained and this was used as the inoculant for the fermentation process.

Fermentation

Wort collected after brewing was transferred into Carlsberg's vessels. About 150 ml of the propagated inoculant with a yeast count of about 22 million cells/ml was introduced into the fermenting vessels using an injection syringe. The flask was shaken vigorously and kept in the refrigerating incubator with an inserted thermometer to monitor the temperature. Fermentation was allowed to proceed for nine days and the pH, temperature, color, gravity, yeast count, attenuation, yeast viability and yeast consistency were monitored and determined daily.

pH determination

The pH was determined using a Jenway 3015 pH meter. Ten milliliter of fermenting wort was taken and the electrode of the pH meter was inserted into the wort sample. The reading on the screen of the pH meter was observed and recorded daily. The pH value of wort after brewing, that is, 1st day of fermentation is found in Table 1 (24 h after the addition of yeast).

Colour determination

The color of wort before and after fermentation was recorded. The wort sample was put in a color comparator (colorimeter). The color of the wort at 320 nm wavelength was measured with the color comparator and the values recorded. The color of wort before fermentation was recorded in Table 1.

Yeast viability and consistency

About 5 ml of fermenting wort was placed in a test-tube, two drops of methylene blue was added to the sample, the sample was vigorously shaken and one or two drops of the stained sample was placed on the haemocytometer, mounted on the microscope and observed. The dead cells which absorbed the stain and retained the blue stain of the methylene blue was expressed as the percentage of the living cells (Peppler, 1978). Yeast viability is calculated as follows:

$$\frac{\text{Total number of cells} - \text{Dead cells}}{\text{Total number of cells}} \times 100$$

Yeast consistency was carried out by placing about 20 ml of fermenting wort in a cuvette. The cuvette was placed in the chamber of a Heraeus Christ Labofuge centrifuge. The sample in the cuvette was spinned at 4000 rpm. After spinning, the supernatant was discarded and the compressed yeast was weighed and recorded. This experiment was carried out in duplicates and the result was calculated as follows (Rose, 1977):

$$\text{Tube 1} = \frac{e - a}{c - a} \times 100\%$$

$$\text{Tube 2} = \frac{f - b}{d - b} \times 100\%$$

Table 1. Gravity value, pH color, temperature and attenuation limit of substrate after brewing (24 h).

Malt /adjunct ratio	pH	Color (EBC)	Gravity (°P)	Temperature (°C)	Attenuation
100% Barley malt	4.98	5.25	11.0	10.5	2.0
90% barley: 10% sorghum	4.87	5.25	11.0	11.2	2.0
80% barley: 20% sorghum	4.48	5.75	11.2	10.8	2.0
70% barley: 30% sorghum	4.86	6.50	11.3	11.5	2.0
60% barley: 40% sorghum	5.00	7.00	11.5	13.2	2.0

Where: weight of tube 1 = a, weight of tube 2 = b, weight of tube 2 + fermenting wort = d, weight of tube 1 + fermenting wort = c, weight of tube 1 + compressed yeast = e, weight of tube 2 + compressed yeast = f.

Attenuation determination

The attenuation was calculated by expressing the final gravity as a percentage of the original gravity, that is:

$$\frac{Og - Fg}{Og} \times 100\%$$

After fermentation, the green beer was filtered to remove the yeast cells. The clear beer was then checked for final gravity, pH, color and alcohol. The alcohol content was determined using the Variag Hans Carl alcohol chart. On this chart, the original gravity (Og) and final gravity (Fg) of the beer was used to determine the specific gravity (Sg), real extract (Re), refractive index (RI) and alcohol content of the beer for each formulations (Kunze,1996) (Table 2).

RESULTS AND DISCUSSION

pH

In the different formulations, it was observed that pH was between 4.48 in 80% barley: 20% sorghum to 5.00 in 60% barley: 40% sorghum. These pH values still conform with the desired pH range of wort, which is between 4.0 and 5.4 (Kunze, 1996), Table 2 shows the pH values of the wort.

Colour (EBC –European brewery convention)

The color of the wort increased with increase in adjunct concentration from 5.25 in 100% barley malt wort to 7.00 in 60% barley: 40% sorghum adjunct (Table 1). This could be attributed to the color of raw sorghum used due to the presence and oxidation of polyphenols and melanoidin in the sorghum, though not toxic, but inimical to producing good beer (Brauhaase, 2000).

Gravity

The gravity of the wort increased with increase in the adjunct proportion (Table 2). This implies that sorghum adjuncts contain more fermentable sugar than barley malt due to the high starch content of sorghum. However very little of the soluble protein is contributed to the wort by sorghum (about 5% of their total protein) Brauhaase, 2000).

Temperature

The temperature of fermentation was maintained at between 10 to 13.3°C. This is to allow for initial vigorous fermentation. A low initiating temperature may lead to too sluggish fermentation due to cold shock that could be experienced by the yeast cells on pitching while a higher temperature would lead to too vigorous fermentation thereby producing unwanted by product, which could affect the quality of the final beer (Hough et al., 1977).

Attenuation

The attenuation values of all the formulations were recorded in Table 2. All values are within the specified limit (1.5 to 2.5). The essence of attenuation is to know at what value the primary fermentation, (verified using the saccharometer spindle) should be terminated so that enough extract will be available for secondary fermentation in the storage tanks. The attenuation values of all the formulation ranged between 2.0 to 2.4 as recorded in Table 2.

Brewing

During brewing process, it was observed that the brew with 40% sorghum adjunct took a longer period of time to saccharify (30 min) as compared to the brews with lower adjunct proportion (8 to 10 min). It was also observed that the filtration rate of the high adjunct proportion brew was slower than the other formulations. This could as a result of the endosperm hardness of the sorghum grains (Malomo, 1993).

Fermentation

During fermentation, the green beer in all the

Table 2. Parameters monitored during fermentation: temperature, pH, attenuation limit (apparent and deformed yeast).

Days of fermentation	Temperature					pH					Attenuation limit (fermented extract)					Deformed yeast				
	100	90:10	80:20	70:30	60:40	100	90:10	80::20	70::30	60:40	100	90:10	80:20	70:30	60:40	100	90:10	80:20	70:30	60:40
Day 1	13.5	12.0	10.2	12.6	10.8	4.98	4.96	4.43	4.86	5.00	2.0	2.0	2.4	2.0	2.0	-	-	-	-	-
Day 2	12.8	12.2	12.0	10.8	10.8	4.80	4.90	4.33	4.49	4.63	7.82	14.54	28.6	18.6	16.03	-	-	-	-	-
Day 3	10.8	12.6	11.9	10.8	11.4	4.51	4.64	4.21	4.35	4.20	12.73	21.81	32.14	34.5	33.0	-	-	-	-	-
Day 4	10.6	12.4	11.8	10.7	12.0	4.21	4.52	4.18	4.32	3.73	18.26	41.86	69.6	50.4	59.8	-	-	-	-	-
Day 5	10.4	11.4	11.6	10.6	10.2	4.10	4.40	4.02	4.44	3.70	34.78	45.4	79.5	60.17	70.4	-	-	-	-	-
Day 6	10.4	10.6	10.8	10.2	10.2	4.08	4.08	4.02	4.26	3.75	44.34	47.2	80.4	72.6	82.6	-	-	-	-	-
Day 7	9.0	10.0	8.6	8.6	10.0	4.06	4.06	4.00	4.30	3.76	63.47	782	81.25	77.9	84.3	-	-	-	-	-
Day 8	8.5	8.2	7.5	7.5	8.2	4.02	4.04	3.88	4.32	3.77	82.6	83.6	81.25	85.0	87.0	-	-	-	-	+
Day 9	6.2	6.5	5.0	6.8	5.0	4.0	4.0	3.80	4.15	3.72	84.34	89.0	82.14	89.3	89.56	-	-	-	-	+

formulations were covered with white layers of foam. As fermentation progressed, the bubbles became fluffy and form brown caps. The appearance of bubbles showed that fermentation was progressing favorably (Kunze, 1996). Towards the end of fermentation, the high crest of foam formed slowly collapsed and the foam appeared browner and the bubbles became less pronounced. This showed that fermentation process had slowed down, less carbon dioxide was been produced and fermentation was slowly going to an end (Kunze, 1996).

Gravity

The amount of fermentable sugars reduced as fermentation progressed. This is because the yeast cells utilized these sugars which were converted to ethyl alcohol and carbon dioxide. The gravity of wort dropped at almost 24 h during fermentation. This is because about 3% of the extract were fermented every 24 h (Brauhaase, 2000). The gravity fall corresponded with an increase in the yeast population. This is because yeast cells multiply when the nutrients were available in the medium. An increase in yeast population indicated that more yeast cells utilized the sugar in the wort more readily, thereby bringing down the gravity of the wort. The peak of the yeast population was recorded on the 4th day of fermentation in all cases of formulations except the 60:40% malt adjunct proportion. This inconsistency could be as a result of early depletion of the nutrients in the substrate. It is known that the higher the adjunct, proportion, the lower the availability of free amino nitrogen in the substrate. This is because the protein in the adjunct is deposited in the crude (unhydrolysed) form and so the amino acid in the form of α-amino nitrogen is not readily available for yeast nutrition (Kunze, 1996).

In all the other formulations, after the 4th day of fermentation, yeast population dropped gradually. The metabolic activity of the cells reduced drastically due to the depletion of nutrients in the medium, eventually resulting in the settling down of the yeast cells called yeast flocculation. However, further drop in gravity was observed until the gravity of the wort was between 1.2 to 2.0°P on the 9th day of fermentation (that is, the final gravity, FG). The original gravity of the wort (gravity on the first day of fermentation) ranged between 11.0 to 11.5° P. The extract fermented by the yeast cells was calculated using the formula shown as:

$$\frac{OG - FG}{OG} \times 100\%$$

Temperature

The temperature of the fermenting medium ranged between 10.2 to 13.2°C. The temperature of the fermenting wort was maintained at between 10.8 to 12.8°C. This was to allow the yeast cells to act at their optimum temperature. As yeast cells act well at this temperature range (Pollock, 1981). It should be noted that the temperature in the fermenting vessel was controlled by a cooling device (refrigerating incubator), because metabolic activity of yeast cells would lead to temperature increase inside the fermenting liquor, which would

Table 3. Original gravity, final gravity, specific gravity, real extract, refractive index, and alcohol of fermented extracts.

Proportions	Original gravity	Final gravity	Specific gravity	Real extract	Refractive index	Alcohol
100% Barley malt	11.5	2.0	1°°/602	3.84	36.5	3.95
90% Barley : 10% sorghum	11.0	1.8	1°°/702	3.95	36.45	3.61
80% Barley : 20 % sorghum	11.2	2.1	1°°/820	4.20	37.38	3.90
70% Barley : 30% sorghum	11.3	1.7	1°°/663	3.80	36.50	3.78
60% Barley : 40 % sorghum	11.5	1.5	1°°/585	3.75	36.35	3.90

lead to an increase in fermentation rates and therefore reduces fermentation period. The cumulative effect of this action is the production of unwanted by-products such as more diacetyl. The foam and colloidal stability of the beer may worsen. From the 6th day of fermentation, a drop in temperature was observed. This was because the metabolic activity of the yeast had greatly reduced. The low temperature observed also assisted in yeast flocculation (Kunze, 1996).

pH

The pH of the pitching wort ranged between 4.43 to 5.00 at Day 1.Ideally, the pH of any pitching wort is between 4.5 to 5.6 (Goldammer, 2002). As fermentation progressed, the pH decreased until the final day. The pH values ranged between 3.75 in 60: 40 malt/adjunct to 4.15 in 70:30 malt adjunct ratio. The reduction in pH values of the fermenting liquor could be as a result of the production of organic acids, uptake of ammonium ions, and the use of primary phosphate ions by the yeast (Kunze, 1996). A drastic fall in pH observed in the 60:40 malt/adjunct ratio s not desirable in the beer because it imparts acidic taste to the beer (Hough, 1977). This low pH value also affected the growth and performance of yeast cells in the fermenting wort. Generally speaking, the pH desired by any brewer is between 4.2 and 4.4 (Brauhaase, 2000).

The fluctuation in the pH in the fermenting wort on Days 5 and 7 of the 70:30 malt/adjunct ratio and in 60:40 malt/ adjunct ratio on Days 6, 7 and 8 could be as a result of yeast autolysis (Kunze, 1996). This results from the process of self digestion of the yeast cells when there is an early depletion of nutrients in the wort (Kunze, 1996).

Yeast count

Yeast count increased progressively in all generations as observed from Day 2 to 4 of fermentation. It followed a normal growth curve whereby growth increased exponentially after introducing a microbe into a nutrient until limiting growth factors bring it down (Pollock, 1981). In this fermentation, the yeast in the 60:40 malt/adjunct proportion was not consistent. The yeast dropped after Day 2 of fermentation. This could be due to the high percentage of adjunct and because of the low value of the free amino nitrogen in the wort, essential nutrient likes, amino acids, lysine, and nitrogen were not available for proper yeast nutrition and nourishment.

Alcohol content

The desired alcohol content of beer is generally 3.92 ± 0.08% (Pollock, 1981). All formulations however produced beer of desired alcohol level. Considering the high extract fermented in 60:40 malt/adjunct ratio (Table 3), it was expected that the alcohol content should be higher than other formulations (Table 3). This could be related to the fact that most of the available nutrients in the medium had been used up for yeast nutrition and nourishment rather than for alcohol production. Table 3 shows the original gravity, final gravity, specific gravity, real extract, refractive index and alcohol content of all the formulations.

Apparent attenuation (fermented (real extract)

Apparent attenuation is the total amount of fermented extract in the wort. From the experiment, it was observed that the highest quantity of fermentable extract was recorded in the 60:40 malt /adjunct formulation (89.5°P) while the least observed was recorded in 80:20 malt/adjunct (82.14°P). The high extract percentage used up by yeast in the 0:40 malt /adjunct formulation showed that most of the extract had been utilized by yeast during primary fermentation. This would undoubtedly have a negative effect on the secondary fermentation, which is the maturity stage of the beer (Anon, 1972). Table 3 shows the values of fermented extract for each formulation.

Conclusion

All proportions of malt/adjunct ratio produced beer of desirable physico chemical parameters; however, 60:40 malt adjunct ratio produced beer with low pH which could have deleterious effect on the beer and the yeast cells

used in fermentation. The emergence of deformed yeast after fermentation showed that the 60:40 formulations did not contain enough nutrients for yeast nutrition and metabolism.

Since the aim of every brewing outfit is to be able to compete favorably in the highly competitive Nigerian beer market as well as to produce beer of optimum quality, it is advisable to stick to beer produced with malt /adjunct proportion of up to 70:30 malt /adjunct proportion whose yeast behavior can be scientifically predicted to avoid deleterious side effects like fusel oil production,that is, higher alcohols, acid, sulfide and other volatile compounds which could affect the quality of the beer. Also a good beer yeast is expected to be used up to 8 to 10 generations (Pollock, 1981). The emergence of deformed yeast in the 60:40 malt /adjunct ratio in the first generation showed that the yeast used might not be able to withstand the stress of long usage.

However the use of external enzymes like amylase, protease and filtrase could assist in bringing out optimum activity when using sorghum adjunct in a higher proportion as in 60:40 malt adjunct proportion. The use of higher percentage of adjunct should therefore be explored putting in consideration the use of external enzymes which although would give desired end product but will be more finance intensive.

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