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THE INFLUENCE OF BREWING WATER ON THE ORGANOLEPTIC PROPERTIES OF BEERS PRODUCED FROM NIGERIAN SORGHUM VARIETIES

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ABSTRACT

This study was carried out to investigate the influence of brewing water on the organoleptic properties of beers produced from Nigerian sorghum varieties. Two sorghum (red and white) were purchased, analysed (grain analysis) and malted (floor malting). Malt analysis was also done before milling (coarse). With the use of exogenous enzymes (α-amylase, β-amylase, β-glucanase and proteinase), eight samples (four from each of the red and white sorghum malts) were mashed (infused) using four distinct water samples (distilled water, sachet water, well water and borehole water)to get worts of varying concentrations. The samples were labelled RA, RB, RC, RD, WA, WB, WC, and WD according to the water type used. The physicochemical properties of the worts were analysed. The worts were boiled with hops for one hour and thirty minutes, they were cooled and pitched with yeast strain Saccharomyces cerevisiae to begin primary fermentation which lasted seven days followed by secondary fermentation for fourteen days. The results of the physicochemical properties of the worts showed original gravity of the samples mashed from distilled water was 1.024° and 1.021° (for red and white sorghum mash, respectively), sachet water 1.026° (for both red and white sorghum mash), well water 1.022° and 1.024° (for red and white sorghum mash, respectively) and borehole water 1.023° and 1.025° (for red and white sorghum mash, respectively). The pH of the samples ranged from 5.3 – 5.6 while the wort viscosity ranged from 1.04 to 1.09cp. Beer analysis results ranged from 1.001–1.002° for all samples with traces of sugar left. The pH of the beer samples range from 3.98–4.01. The percentage alcohol produced ranged from 2.58–3.23% and the apparent fermentability of the samples ranged from 91.3–96.15%. Based on the parameters (color, taste, mouthfeel, and general acceptability) examined at the $P \leq 0.05$ level of significance, the results indicated that there was no statistically significant difference between the samples. In conclusion, these findings of the study revealed that the organoleptic qualities of beer made from red and white sorghum types are unaffected by the different water sources (distilled water, sachet water, well water, and borehole water) utilized

Keyword: Organoleptic, brewing water, beer, sorghum, alcohol

INTRODUCTION

Beer is globally popular alcoholic beverage prepared from a grain malt, water, hops and yeasts (Sawadogo-Lingani *et al.* 2023). Brewing technology is constantly evolving, and this opens the possibility of exploring the brewing processes more deeply (Adetunji *et al.* 2013; Li *et al.* 2017). Water is a crucial but frequently overlooked element in the manufacturing of beer because it makes up approximately 94% of the beverage (Punčochářová *et al.* 2019). The composition of the brewing water should therefore be one of the properties that is researched. Each beer style calls for a different composition of brewing water (Bejiga and Dasa, 2024; Buiatti, 2009).

Water can come from two sources—surface water and groundwater (Fillaudeau *et al.* 2016). The former has more organic matter but fewer dissolved minerals, whereas the later often has more dissolved minerals and less organic matter. Some brewers even use their own water sources, which adds uniqueness to their goods. Beer makers can request reports from nearby water providers, ship samples of water to labs, or conduct the tests themselves with the right tools to ascertain the mineral makeup of the water (Eumann and Schildbach, 2012). The following describes the typical test parameters. The findings allow brewers to modify the water content as needed to create a wonderful beer. The chemical and sensory properties of beer are also significantly impacted by water (Montanari *et al.* 2009).

The most common elements in water are salts of calcium and magnesium. Term of water hardness is used for the description of the content of calcium and magnesium salts (Montanari *et al.* 2009). It represents the sum of calcium, magnesium and barium ions, or is the content of all cations with a charge greater than one. The amount of calcium and magnesium bicarbonates in water is correlated with its carbonate hardness. When the wort is boiled, bicarbonates are decomposed by removing carbon dioxide to create more or less soluble carbonates (Fillaudeau *et al.* 2016). Non-bicarbonate water hardness (stable) consists of calcium and magnesium salts of sulfuric acid, hydrochloric acid, nitric acid and others. These components are not affected by the wort boiling (Anderson *et al.* 2019).

Water hardness is important in assessing the quality of water used in brewing (Punčochářová *et al.* 2019). As a result, several types of brewing water were allocated based on the type of a produced beer, one of them is Pilsner water. It is appropriate for intensely hopped bottom-fermented beers and is a soft water with a low percentage of inorganic components. To produce strongly hopped top-fermented ales, Burton on Trend is used (Montanari *et al.* 2009). This kind of water has a high sulfate content and is extremely hard. Other well-known brewing waters types are Munich, Dortmund and Vienna. Other important parameters which correlates with water hardness are pH and ionic strength (Xu *et al.* 2017).

Low amounts of dissolved salts in water have a substantial impact on the beer's flavor, enzymatic activity during mashing, and the processes that control the wort's boiling, cooling, and fermentation (Fillaudeau *et al.* 2016). For example, calcium ions may be present in high amounts in water (up to 200 mg/l) (Xu *et al.* 2017). Calcium is essential because it reduces the pH of mash by interactions with phosphates and malt proteins. Decreasing the pH is beneficial for optimal function of some malt enzymes – it promotes stability of α-amylase against thermal denaturation (Punčochářová *et al.* 2019). Calcium silicate also causes a beer gushing. Magnesium ions stimulate yeast enzyme activity during fermentation and is a cofactor for some enzymes. Alkaline metals are found in water at lower concentrations, higher concentrations are in barley malt. It shows inhibitory effect on some malt enzymes, but it has positive physiological significance during fermentation (Diaz *et al.* 2022). Metals are also present at various concentrations in water. It is enzymes cofactor and influences proteolytic degradation of malt. High content of metals causes dark colour of mash and beer foam and the mashing slows down. This reduces the fullness of flavour and the bitterness of the beer (Konfo *et al.* 2015). Another parameter of the beer, which can be affected by the composition of brewing water is content of vitamins of the B group. Main sources of the vitamins of B group are malt and yeast activity. Biologically active forms are associated with enzyme complexes involved in various metabolic processes such as Citric cycle, β-oxidation, electron transport and other biochemical reactions (Konfo *et al.* 2015). Damaged or dead cells may release the vitamin into the solution, so it can easily end up in the final product during beer production (Punčochářová *et al.* 2019).

Brewing is just one of the many industrial operations that depend heavily on water. Water is used by brewers in three main ways: as product water, which makes up the majority of beer (92%) and is used for mashing, sparging, diluting beer brewed at high gravity, and adding hop extract or diatomaceous earth for filtration, among other things; as process water, which is used to clean and sanitize the plant and pack beer transfer lines, among other things; and as service water, which is used to raise steam for the transportation of heat energy throughout the brewery (Fillaudeau *et al.* 2016). Each use requires somewhat different water quality. For every volume of beer produced, brewers consume four to possibly twelve volumes of water overall, depending on their efficiency; process and service water are the main water demands in a brewery, where very soft water is preferable (Punčochářová *et al.* 2019). Large breweries tend to be more efficient in water usage than small ones (Xu *et al.* 2017).

Since the majority of beer is water, the quality of the brewing water can have an impact. In addition to being the primary ingredient in beer, the availability of water has increasingly become a location factor, particularly for breweries with enormous capacities. This demonstrates how crucial water supply and treatment are. Thankfully, advancements in water treatment technology have made it possible to use water sources that were previously thought to be unsuitable for brewing. Each of the several water sources that are available for brewing has unique qualities of its own. Checking the water quality during the brewing process is an essential step in producing beer with a remarkable flavor and quality. It is now usual for breweries to adjust the composition of the brewing water they use irrespective of the source to meet standard. Hence, this study.

This study is aimed at investigating the influence of brewing water on the organoleptic properties of beers produced from Nigerian sorghum varieties. The specific objectives of this study are to:

i. To determine the quality of the sorghum grain used and its malt properties.
ii. To mash sorghum grist using different water sources by infusion mashing technique
iii. To determine the physicochemical properties of the worts produced
iv. To determine the effect of the different water sources on the organoleptic properties of the beer produced
v. To determine the organoleptic properties of the beer produced

MATERIALS AND METHODS

Sources of Materials Used

The four basic raw materials used for these research were water (distilled water, sachet water, well water, borehole water), malts (red and white sorghum variety), hops and yeast. The red and white sorghum variety were purchased from Eke-Agbani Market in Nkanu-West LGA of Enugu state. The hops, yeast, chemicals and reagents used were supplied by the Laboratory of the Department of Applied Microbiology and Brewing, ESUT.

Methods Used

The methods used in this work were according to that of Institute of Brewing (IOB), America Society of Brewing Chemists (ASBC) and European Brewing Convention (EBC) methods.

Grain Analysis

The red and white sorghum grains were analysed for their germinative energy, germinative capacity, moisture content and thousand corn weight using the Institute of Brewing (IOB) method of analysis.

Malting Process

The process of malting involved first selecting the grain, then steeping it for 40 hours (changing the steep liquor every 6 hours and letting the grains air-rest for 2 hours), casting it for 24 hours (draining the water and heaping it on a jute bag), germination (spreading the grains evenly on the jute bag for even aeration and germination) for 3 days, and kilning (drying the malt to lower its moisture content).The rootlets were extracted using fiction (abrasion) following kilning.

Malt Analysis

The malted grains were analysed for hot water extract, cold water extract and diastatic power.

Milling Process

The malts were coarsely milled in the form that ensures that the husks are substantially left intact in order to aid filtration after mashing.

Mashing Process

The type of mashing used for this study was infusion mashing technique. The milled red and white sorghum grists were weighed 50g each into 8 different cleaned 500ml conical flask labelled A, B, C, D, E, F, G and H.

Sample A contained 50g of red sorghum mashed with distilled water.
Sample B contained 50g of red sorghum malt mashed with sachet water.
Sample C contained 50g of red sorghum malt mashed with well water.
Sample D contained 50g of red sorghum malt mashed with borehole water.
Sample E contained 50g of white sorghum malt mashed with distilled water.
Sample F contained 50g of white sorghum malt mashed with sachet water.
Sample G contained 50g of white sorghum malt mashed with well water.
Sample H contained 50g of white sorghum malt mashed with borehole water.

A total of 360ml of each water sample used was added into each of the conical flask as labelled above. One millilitre (1ml) of each exogenous enzyme (thermamyl (-amylase), fungamyl (-amylase), neutrase (proteinase) and amyloglucosidase) were added into each of the conical flask containing the samples and shake properly. The labelled conical flask containing the samples were covered with aluminium foil and placed in a water bath. Heating commenced following the processes of an upward infusion mashing system. The temperature was raised to 36°C and kept for after which it was raised to 43°C and maintained for 30mins for Beta-glucanase activities. The temperature was raised to 50°C and kept at rest for 30 minutes for proteolysis. It was followed by a gradual increase in temperature from 63°C and kept at rest for 1hr for β-amylase activities. Finally, the temperature was increased from 73°C for alpha-amylase activities and test was observed for 10 – 20 minutes after which saccharification test was carried out. To mash off, the temperature was raised to 80°C, and heating was maintained until saccharification was accomplished. The samples (mashes) were allowed to cool and filtered using filter cloth to obtain a clear solution known as worts.

Wort Analysis

The parameters determined were original gravity (O.G) (°), sugar (°Brix), pH, flow rate (sec), viscosity (cp), temperature (°C) and reducing sugar (glucose and maltose). This was done using the method of the Methods of Analysis of the Institute of Brewing.

Wort boiling

This was done in order to remove the hop components, sterilize the worts, and deactivate the enzymes prior to fermentation. Worts were placed in a pot on a burning gas cooker after being poured into a 500 ml conical flask. Isomerized hops extract was added and boil for $1^1/_2$ hours.

Wort cooling and filtration

The hopped boiled worts were cooled to room temperature using heat exchanger technique by placing the conical flasks in a big basin containing cold water. The separation of hop debris and the coagulant protein (trub) from the wort was done with the help of sterile muslin cloth and filter.

Wort fermentation

The cooled and aerated worts were now ready for pitching with subsequent yeast fermentation. The specific gravity was also determined using hydrometer. Care was taken during this measurement to reduce microbial attack on the wort at this stage. Strain of *Saccharomyces cerevisiae* was employed for the fermentation process. The yeast was first reconstituted by mixing 20g of yeast, 10g of glucose and water in a container. It was shaked vigorously for 10mins and checked for pressure which signified that the yeast was back to life. Ten (10)ml of yeast was added to the 300ml of wort (pitching) and the container was stocked with cotton wool. The primary fermentation took 7days. At the end the yeast was skimmed off and the product filtered to obtain beer which was left for 7days for secondary fermentation. After the secondary fermentation, the beer was filtered with filter paper to obtain a bright clear beer.

Beer Analysis

After fermentation, the pH, gravity and percentage alcohol were determined after filtration.

Sensory Evaluation

Sensory evaluation test was carried out at the end of the beer maturation. A group of ten panelists tested the products and recorded their inferences and insights about the product. The evaluation varied from “dislike extremely” to “liked extremely” for parameters (colour, taste, mouth feel and general acceptability). The result of their judgment were subjected to statistical analysis.

Statistical Analysis of Data

The data collected from organoleptic analysis of the beer sample were subjected to a one-way analysis of variance (ANOVA) at 95% confidence level and means that differed were considered significant at $P \leq 0.05$ (five percent level of significance).

RESULTS

Table 1 shows the result of grain analysis indicating that the red and white sorghum variety used for this study possesses good grain quality required for brewing. Table 2 presented results of malt analysis indicating that the malt from red and white sorghum grains are suitable for the production of beer. Decantation mashing technique was used to obtain worts of varying properties and concentrations from red and white sorghum malts kilned at varying temperatures. The physicochemical properties of the worts were determined and recorded in Table 3. The table showed result where viscosity decreases with increasing kilning temperature while reducing sugar increases with increasing kilning temperature. The physicochemical properties of the beer samples after three days, primary and secondary fermentation were recorded in Tables 4, 5 and 6, respectively. While table 7 was the sensory evaluation table.

Table 1: Grain analysis

Samples	Germinative Energy (%)	Germinative Capacity (%)	Moisture content (%)	Thousand corn weight (g)
Red Sorghum	98	96	9.6	24
White Sorghum	96	96.5	9.5	29

Table 2: Malt Analysis

Samples	HWE (%/kg)	CWE (%)	Diastatic power (%)
Red Sorghum	295	24	27.3
White Sorghum	264	22	25.1

Table 3: Analysis of the Wort Samples

Samples	Original Gravity (O.G)($^o\rho$)	Sugar (^{o}Brix)	pH	Flow rate (Sec)	Viscosity (cp)	Temp (^{o}C)	Reducing Sugar	
							Glucose	Maltose
A	1.024	6.07	5.4	24.09	1.05	27	50.20	81.10
B	1.026	6.57	5.3	24.68	1.07	27	54.70	88.86
C	1.022	5.58	5.5	25.16	1.09	27	60.15	98.1
D	1.023	5.83	5.3	24.28	1.05	27	50.20	81.10
E	1.021	5.33	5.4	24.01	1.04	27	54.70	88.86
F	1.026	6.57	5.6	24.97	1.09	27	60.15	98.1
G	1.024	6.07	5.4	24.21	1.05	27	60.15	98.1
H	1.025	6.32	5.4	24.32	1.06	27	60.15	98.1

Key:

Sample A contained 50g of red sorghum mashed with distilled water.
Sample B contained 50g of red sorghum malt mashed with sachet water.
Sample C contained 50g of red sorghum malt mashed with well water.
Sample D contained 50g of red sorghum malt mashed with borehole water.
Sample E contained 50g of white sorghum malt mashed with distilled water.
Sample F contained 50g of white sorghum malt mashed with sachet water.
Sample G contained 50g of white sorghum malt mashed with well water.
Sample H contained 50g of white sorghum malt mashed with borehole water.

Table 4: Analysis of the Liquor after three days of Fermentation

Samples	Specific Gravity (S.G) (°ρ)	Sugar (°Brix)	pH	Temp (°C)	% Alcohol (v/v)	Apparent Fermentability (%)
A	1.010	2.56	4.49	25	1.81	58.3
B	1.012	3.07	4.46	25	1.81	53.8
C	1.009	2.31	4.46	25	1.66	59.1
D	1.008	2.05	4.50	25	1.94	65.2
E	1.011	2.81	4.52	25	1.29	47.6
F	1.010	2.56	4.48	25	2.06	61.5
G	1.012	3.07	4.51	25	1.55	50
H	1.011	2.81	4.48	25	1.81	56

Table 5: Physicochemical Analysis of the Green Beers after Primary Fermentation

Samples	Specific Gravity (S.G) (°ρ)	Sugar (° Brix)	pH	Temp (°C)	% Alcohol (v/v)	Apparent Fermentability (%)
A	1.004	1.03	4.12	25	2.58	83.33
B	1.005	1.29	4.08	25	2.71	80.77
C	1.003	0.77	4.10	25	2.45	86.36
D	1.005	1.29	4.09	25	2.32	78.26
E	1.003	0.77	4.07	25	3.32	85.71
F	1.004	1.03	4.10	25	2.84	84.61
G	1.004	1.03	4.08	25	2.58	83.33
H	1.003	0.77	4.11	25	2.84	88

Table 6: Physicochemical Analysis of the Beers after Secondary Fermentation

Samples	Specific Gravity (S.G) (°ρ)	Sugar (°Brix)	pH	Temp (°C)	% Alcohol (v/v)	Apparent Fermentability (%)
A	**1.001**	0.26	3.99	22	2.97	95.8
B	1.002	0.52	4.0	22	3.1	96.15
C	1.001	0.26	3.98	22	2.71	95.45
D	1.002	0.52	3.99	22	2.71	91.3
E	1.001	0.26	4.01	22	2.58	95.24
F	1.001	0.26	4.01	22	3.23	96.15
G	1.002	0.52	4.0	22	2.84	91.67
H	1.001	0.26	4.0	22	3.1	96

Table 7: Sensory estimation for parameters tested

	Parameters			
	Colour	Taste	Mouth feel	General acceptability
F Calculated	1.08	0.16	0.50	0.41
F Tabulated	2.866	2.866	2.866	2.866
Least Significant Differences	0.343	0.522	0.379	0.524

The result of sensory evaluation showed that there was no significant difference among the samples based on parameters tested at $P \leq 0.05$ level of significance. The beer samples are therefore accepted and can be sold to the public.

DISCUSSION

The quality and makeup of the water used to brew beer have a significant impact on its flavor and character. Water quality plays a crucial role in the brewing process since different sources of water have distinct mineral profiles that can either improve or change the flavor of beer. The impact of brewing water on the organoleptic characteristics of beers made from Nigerian sorghum varieties was successfully assessed in this study.

The characteristics of cereal grains (red and white sorghum types) are displayed in Table 1. The of 1000 corn weight of 24g and 29g were smaller compared to 37-47 g for barley reported by Adetunji *et al.* (2013). Nonetheless, it is anticipated that these grains will weigh less because of their smaller size. There were differences in the germinative properties of the cereal grains. For the red and white sorghum cultivars, respectively, germinative energies of 98% and 96%, germinative capacities of 96% and 96.5%, and moisture content of 9.6% and 9.5% were attained. Grain required for malting should have over 90% satisfactory germination qualities, according to Dabija *et al.* (2021). Red and white sorghum cultivars demonstrated promising potential as a malting grain. Good malting barley can be identified by its high germination energy, low moisture level, and high germination capacity.

One important factor in determining the malting quality of grains is malt extract. These are the compounds that are released into an aqueous solution which is, due to its magnesium and calcium ion content, the best solvent for amylolytic enzymes (Agu and Obanu, 2006).The malt analysis findings are shown in Table 2. Red and white sorghum malt had hot water extract values of 264% and 295% kg, respectively, while both varieties of malt had cold water extract values of 24% and 22%. The diastatic power for white and red sorghum malt was 25.1% and 27.3%, respectively. The result is consistent with previous works (San Martin-Gonzalez *et al.* 2021). These findings proved that the recommended volume of beer production can employ malt from red and white sorghum grains. It is believed that with a higher diastatic power, there is possibility of higher extract yield.

The samples had a satisfactory fermentable extract yield (original gravity) when mashed with different types of water, according to the data. The original gravity of the wort from red and white sorghum mash samples obtained from distilled water is 1.024° and 1.021°, respectively; for the sachet water, it is 1.026° (for both types of mash); for the well water, it is 1.022° and 1.024° (for both types of mash); and for the borehole water, it is 1.023° and 1.025° (for both types of mash). The samples' wort viscosity varied from 1.04 to 1.09cp, while their pH ranged from 5.3 to 5.6. Low malt extract value in the sorghum malt sample despite its higher starch content were predictable due to the insufficient concentration of enzymes in sorghum and not the type of water used.

Alcohol was a by-product of fermentation that varied in concentration depending on the gravity content of each wort sample. All samples that had residual sugar experienced a reduction in specific gravity to within the range of 1.001–1.002° due to the activity of yeast on the samples. The beer samples had pH values ranging from 3.98 to 4.01. The alcohol produced during fermentation causes the beer samples to become acidic. The apparent fermentability of the samples ranged from 91.3 to 96.15%, whereas the percentage of alcohol generated varied from 2.58 to 3.23%. This findings are in consonance with the findings of other researchers (Agu ad Obanu, 2006; Diaz *et al.,* 2022; Ofoedu *et al.,* 2021). The alcoholic content of the two samples contain percentage that is within the normal range as stipulated by National Agency for Food and Drug Administration and Control (NAFDAC).

The findings of the sensory evaluation of the organoleptic properties of the beer produced at the $P \leq 0.05$ level of significance were shown in Table 7. Based on the parameters (color, taste, mouthfeel, and general acceptability) examined at the $P \leq 0.05$ level of significance, the results indicated that there was no statistically significant difference between the samples. When the organoleptic properties of the samples were analyzed statistically, it was revealed that there was no discernible difference between them and that the water used for mashing in this study, which came from various sources, did not affect the beer's final organoleptic qualities.

CONCLUSION

In conclusion, this findings of the study revealed that the organoleptic qualities of beer made from red and white sorghum types are unaffected by the different water sources (distilled water, sachet water, well water, and borehole water) utilized. The water (distilled water, sachet water, well water, and borehole water) used are suitable for brewing and can be used to produce beer of acceptable organoleptic properties, as statistical analysis shows no significant difference among the samples.

The following recommendations were made

- These preliminary laboratory studies indicate that cheaper local raw material could be used in brewing thereby reducing the production cost as well as capital outlay. However, pilot plant trials are necessary to arrive at a definite conclusion.
- It is therefore recommended that further studies have to be conducted using a different malting procedure and also, other local cereals have to be tried to see if the outcome will be better and also.
- Brewers in Nigeria and the world over should adopt the use of sorghum for brewing since the grains have good brewing quality and is readily available as the climate condition in Nigeria favours its growth.
- By using sorghum in brewing, for edible food and feed for animals, it will help to promote agriculture thereby boosting Nigeria's economy.
- Adequate water treatment procedures should be put in place to standardize water used for brewing.
- Further studies should be performed on the physicochemical properties of the water used for brewing.

REFERENCES

Adetunji AI, Khoza S, de Kock HL. and Taylor JR. (2013). Influence of sorghum grain type on wort physicochemical and sensory quality in a whole-grain and commercial enzyme mashing process. *Journal of the Institute of Brewing*, *119*(3): 156-163.

Agu RC and Obanu ZA. (2006). Studies on beer production from Nigeria sorghum. *Journal of Food and Technology*, *28*:81-83.

Anderson HE, Santos IC, Hildenbrand ZL. and Schug KA. (2019). A review of the analytical methods used for beer ingredient and finished product analysis and quality control. *Analytica Chimica Acta*, *1085*: 1-20.

Bejiga T. and Dasa E.W. (2024). Comprehensive review of the potential of sorghum in malt and beer production. *Journal of Advances in Food Science and Technology*, *11*(2): 10-21.

Buiatti S. (2009). Beer composition: An overview. *Beer in Health and Disease Prevention*, *14*: 213-225.

Dabija A, Ciocan ME, Chetrariu A. and Codină GG. (2021). Maize and sorghum as raw materials for brewing, a review. *Applied Sciences*, *11*(7): 31-39.

Eumann M. and Schildbach S. (2012). 125th anniversary review: Water sources and treatment in brewing. *Journal of the Institute of Brewing*, *118*(1): 12-21.

Fillaudeau L, Blanpain-Avet P. and Daufin G. (2006). Water, wastewater and waste management in brewing industries. *Journal of cleaner production*, *14*(5): 463-471.

Konfo CTR, Chabi NW, Dahouenon-Ahoussi E, Cakpo-Chichi M, Soumanou MM. and Sohounhloue DCK. (2015). Improvement of African traditional sorghum beers quality and potential applications of plants extracts for their stabilization: a review. *The*

Journal of Microbiology, Biotechnology and Food Sciences, *5*(2): 190-197.

Li Q, Wang J. and Liu C. (2017). Beers. In *Current developments in biotechnology and bioengineering.* Elsevier. pp: 305-351.

Montanari L, Mayer H, Marconi O. and Fantozzi P. (2009). Minerals in beer. In *Beer in health and disease prevention.* Academic Press. pp: 359-365.

Ofoedu CE, Akosim CQ, Iwouno JO, Obi CD, Shorstkii I. and Okpala COR. (2021). Characteristic changes in malt, wort, and beer produced from different Nigerian rice varieties as influenced by varying malting conditions. *Peer Journal*, *9*: e10968.

Punčochářová L, Pořízka J, Diviš P. and Štursa V. (2019). Study of the influence of brewing water on selected analytes in beer. *Slovak Journal of Food Sciences/Potravinarstvo*, *13*(1): 507-514.

Sawadogo-Lingani H, Owusu-Kwarteng J. and Jespersen L. (2023). Sustainable Production of African Traditional Sorghum Beers. In *Natural Products in Beverages: Botany, Phytochemistry, Pharmacology and Processing* Cham: Springer International Publishing. pp: 1-30.

Xu YQ, Zou C, Gao Y, Chen JX, Wang F, Chen GS. and Yin JF. (2017). Effect of the type of brewing water on the chemical composition, sensory quality and antioxidant capacity of Chinese teas. *Food Chemistry*, *236*: 142-151.