African Journal of Food Science and Technology (ISSN: 2141-5455) Vol. 14(7) pp. 1-13, June, 2023

DOI: http:/dx.doi.org/10.14303//ajfst.2023.030

Available online https://www.interesjournals.org/food-science-technology.html

Research Article

Enhancement of the Quality and Safety of Traditional Banana Beer Using Bio-Process

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Abstract

This research study was undertaken to enhance the quality and safety of traditional banana beer using bio-process. Banana beer samples were produced from blends of banana juice, malted or non-malted sorghum, water, and hops according to the type. *Saccharomyces cerevisiae* was used to ferment both banana beer types. Traditional banana beers (S_1, S_2, and S_3) were produced by fermenting the mixture of banana juice with roasted sorghum. Traditional banana beers acted like control. On the other hand, improved banana beers (S_4-S_{12}) were produced from blends of banana juice, sorghum, malt, hops, and water. High-Temperature Long-Time pasteurization was used. The experimental design was based on Mixture I-optimal design using Design Expert software version 11.0. Experimental constraints were: $0.5 \leq A \leq 0.9$; $0.05 \leq B \leq 0.37$; $0 \leq C \leq 0.05$; $0 \leq D \leq 0.30$, A, B, C and D represented banana juice's brix, sorghum flour/malt, hops, and water respectively. Produced samples were subjected to proximate analysis, alcohol content, methanol, microbial, and sensory analyses. Means were separated using Duncan multiple range test, and a significant difference was accepted at $p<0.05$. The quality parameters showed that the bioprocess method was efficient to improve traditional banana beers.

Keywords: Banana beer, Malting, Bio-process, *Saccharomyces cerevisiae*, sorghum

INTRODUCTION

Banana beer is a weak alcoholic beverage that is popular throughout Africa. It is made by fermenting banana juice with cereal flour, often sorghum flour. This kind of beer is sweet and slightly hazy with a shelf life that may reach up to two weeks under correct storage conditions. The processing method and ratio of ingredients used vary widely from country to country and with personal taste. In Kenya, banana beer made from sorghum or millet flour is known as "urwaga". In Uganda, banana beer is called "lubisi". Rwandan banana beer is called "urwagwa", and it is the most popular traditional alcoholic beverage produced from banana juice obtained from special varieties of bananas, such as "indege, inkati, intutu, kayuku, gisukali and intokatoke". Plantain also can be utilized as a raw material in many rural based cottage industries including the production of wine, vinegar, and local beer, which is important nutritionally as it is described to be very rich in vitamin B-complex due to the high yeast content (Bosso et al., 1994).

The quality and safety of traditional banana beer is still a matter of concern across Africa. Presence of lactic acid bacteria, mould, and coliforms have been reported to be high for artisanal processed banana beer in Rwanda. Modernization and production of western beers influenced a lot of community to shift from t raditional

Received: 20-Apr-2023, Manuscript No. AJFST-23-96632; **Editor assigned:** 24-Apr-2023, PreQC No. AJFST-23-96632 (PQ); **Reviewed:** 16-May-2023, QC No. AJFST-23-96632; **Revised:** 20-Jun-2023, Manuscript No. AJFST-23-96632 (R); **Published:** 27-Jun-2023

Citation: Thierry U, et al. (2023). Enhancement of the Quality and Safety of Traditional Banana Beer Using Bio-Process. AJFST: 030.

beverages to improved and high quality alcoholic products (Chemists et al., 1975). In that regard, the need to improve traditional banana beer came into realization throughout this research. The effort to add value to the product is backed by the fact that bananas are readily available, seasonal, and highly perishable. Banana beer improvement is crucial to the wellbeing of rural farmers and middle income families (Dhar et al., 2013). The beverage is used very often in traditional ceremonies, weddings and other celebration gatherings from rural and urban places. The consumption of banana beer throughout East African countries is higher in rural area. However, modernization and empowering Short and Medium Enterprises (SMEs) by government policies all over the region is changing some of the perceptions and mindsets of the citizens (Wallace et al., 1955).

MATERIALS AND METHODS

Source of raw materials

Starting materials used for both traditional and improved banana beers were purchased overseas and locally in Nigeria. Pectinase and hops (10% flavonoids) were bought from 3109 AA Schiedam Netherland (Harrigan et al., 1976). Brewer’s yeast was purchased from ‘Now foods Ltd’ in Nigeria. Other raw materials were purchased from Ogige market (Nsukka local government Area-Enugu, Nigeria), as follows:

- Bananas (Red Daca and *Musa Cavendish*)
- Sorghum (Sorghum bicolor)
- Distilled water
- Hops (10% flavonoids)
- Yeast (*Saccharomyces cerevisiae*)

Preparation of raw materials

Banana juice preparation: Ripe banana bunches were bought from Ogige market in Nsukka Local government, Enugu state (Nigeria). Bananas were peeled, cut and mashed in food processing laboratory of food science and technology department, university of Nigeria, Nsukka (van Heerden et al., 1987).

Indeed, banana juices were produced with little modification to avoid contamination through screening of raw materials and using enzyme extraction. The reasons to adjust the quality status of traditional banana beers were to protect the assessors during sensory tests of the produced banana beers (Holt et al., 2019). Thus, processing operations that normally involve using hands or feet on spear grasses were not used (Figure 1). However, pectinase solutions (5 grams in 20 ml of distilled water) were used to treat banana puree and extract the banana juice. Firstly, ripened bananas were spilled and put in a blender (Hurtado et al., 2017). Thus, the second stage was to blend 400 grams of banana pulp with 100 ml of water to ease the blending process. Banana juice was obtained by mixing the blend with 10% w/v of pectinase solution (Kanyana et al., 2013). In addition, banana juices were pasteurized using High Temperature Short Time pasteurization (HTST) to avoid contamination in order to reduce foreign yeasts and other microbial competitors (Kubo et al., 2016).

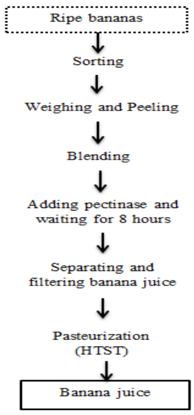

Figure 1: Banana juice production flowchart.

Sorghum flour preparation

Improved banana beers were produced using malted sorghum flour, banana juice, hops, and yeasts. The early processing stage of sorghum malt involved cleaning to remove impurities and damaged grains. After the sorghum was sorted, the next step was the steeping process. Under normal conditions, the steeping process of sorghum grains is supposed to take 24-48 hours at 30°C. Unfortunately, the steeping process lasted for 72 hours due to temperature fluctuations (25-28°C). After 48 hours of steeping, the wet sorghum grains underwent a sprinkling process for 2 hours at 28°C (Lyumugabe et al., 2012).

The seeds started germinating after 72 hours. Germination continued up to the level that the germinated seeds had sprouted roots of approximately 1-2 cm. The temperature inside the germination room was recorded to be 29°C, while the temperature inside the germination bed, where the malting seeds were lying was recorded to be 25-28°C. Germination process was slowed down by sun drying for 3-4 days until it was totally inhibited. Preliminary kilning process was carried out to obtain sorghum malt (Figure 2). This step involves removing of sprouted roots in order to remain with only malted seeds (Lyumugabe et al., 2010). Kilning process was conducted by sun drying 6 hours per day for a period of three days, and the roots were removed manually by abrasion. Finally, 1 Kg of sorghum malt was roasted in an aluminum pot at 150°C for 8-10 minutes and milled with an electric grinder (SSJ-999B, Supper Sonny Japan) where 200 g of malt was grinded for each round. On hand, traditional banana beers were produced using roasted sorghum. Roasted sorghum flours were grinded into minimum flour sizes (not finely grinded). The flours were grinded using the same electric grinder (Massiot et al., 1994). The steps followed while preparing roasted sorghum flour are shown in Figure 3.

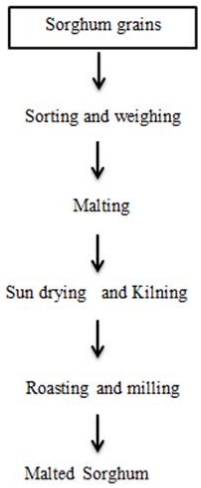

Figure 2: Malted sorghum flour production.

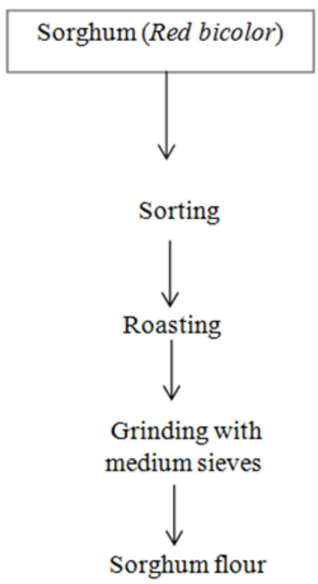

Figure 3: Roasted sorghum flour.

Traditional and improved banana beers production

Traditional banana beer production: Traditional banana beers were produced with little modification in contamination through screening of raw materials and roasting of sorghum (Figure 3). In addition, processing operations that normally involve using hands or feet with spear grasses were not used (Figure 4). Pectinase solution (5 grams in 20 ml of distilled water) was used to treat banana puree to obtain banana juice. Firstly, ripe bananas were spilled and put in a blender

(Mosher, et al., 2017). Secondly, 400 grams of banana pulp with 100 ml of water were blended to ease the blending process. Banana juice was obtained by mixing the blend with 10% w/v of pectinase solution. The mixture was left all over the night (8 hours) for juice extraction. On the other hand, both malted and non-malted/roasted sorghum flours were prepared by grinding sorghum malt and roasted sorghum with an electric grinder (SSJ-999B, Supper Sonny Japan). The mixture constraints and design expert data are shown in Table 1 and 2 below. Finally, yeast (1 g/l) and non-malted sorghum flours were added to the juice (0.028 Kg/l). In fact, sorghum flours that were used to produce traditional banana beers were roasted and grinded with low Rotation Per Minute (rpm) in a grinder to obtain minimum size flours (not finely grinded) (Moskowitz et al., 1971). The traditional banana beer was fermented under a room temperature of 28°C and normal pressure of 1 atmosphere (Navarro et al., 2007).

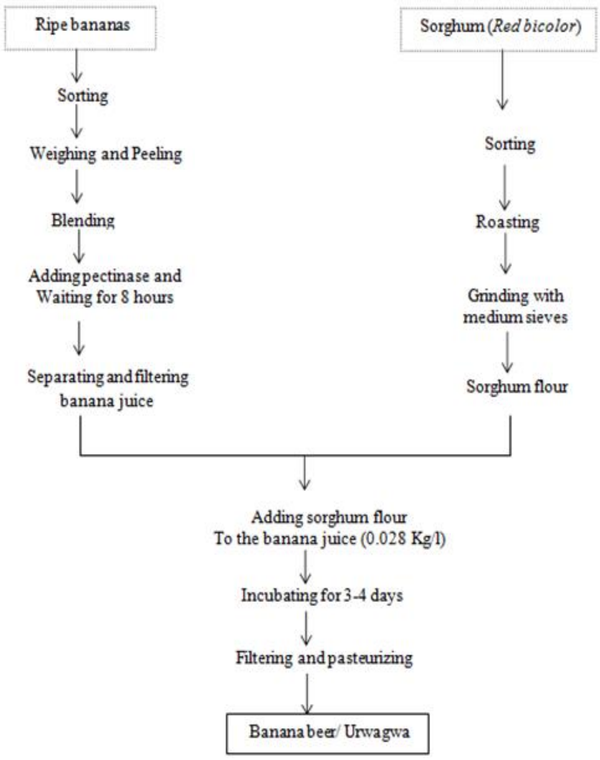

Figure 4: Flow chart for production of traditional banana beer.

Table 1: Mixture constraints for banana beer production.

Component	Name	Units	Type	Minimum	Maximum	Coded Low	Coded high
A	Banana juice	g	Mixture	0.5	0.9	+0↔0	+1↔1
B	Sorghum	g	Mixture	0.05	0.37	+0↔0	+1↔1
C	Hops	g	Mixture	0	0.05	+0↔0	+1↔1
D	Water	ml	Mixture	0	0.3	+0↔0	+1↔1
Total=1.0000 L.Pseudo coding							

Table 2: Design expert's experimental data for traditional and improved banana beers production.

Run	A. Banana juice (g)	B. Sorghum (g)	C. Hops (g)	D. Water (ml)
1	0.6	0.4	0	0
2	0.8	0.2	0	0
3	0.9	0.1	0	0
4	0.63	0.22	0.05	0.1
5	0.5	0.2	0.05	0.25
6	0.75	0.22	0.03	0
7	0.6	0.4	0	0
8	0.7	0.1	0.05	0.15
9	0.6	0.2	0.02	0.18

10	0.5	0.37	0.03	0.1
11	0.55	0.1	0.05	0.3
12	0.82	0.1	0.03	0.05

Improved banana beer production

Banana beers were produced using the bioprocess method. In this method, banana beers were produced by combining pasteurized banana juice with the word from malted sorghum flour. Pasteurization of banana juice was carried out at 95°C for 5 seconds using High Temperature short time. Batch and semi batch fermentation processes were adopted (Nsabimana et al., 2007). Those approaches were assessed to get a hint of the impact of CO_2 upon the fermentation process. Moreover, roasting of malted sorghum was conducted to ease the kilning process at 150°C and adjust banana beer's color. Moreover, hops were added at different ratios in order to increase the aroma and taste of improved banana beer (Figure 5) (Ogbonna et al., 2016).

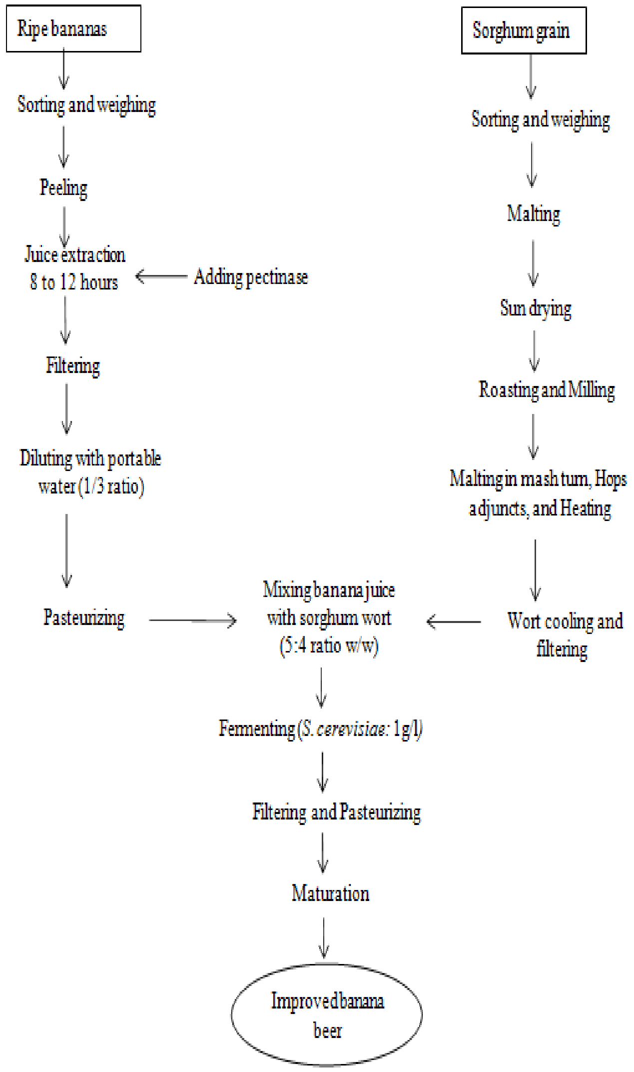

Figure 5: Flow chart for the production of improved banana beer using bioprocess.

RESULTS AND DISCUSSION

Different banana beer samples which were produced during the realization of this research are presented in Figure 6 while their formulation data were given in Table 2.

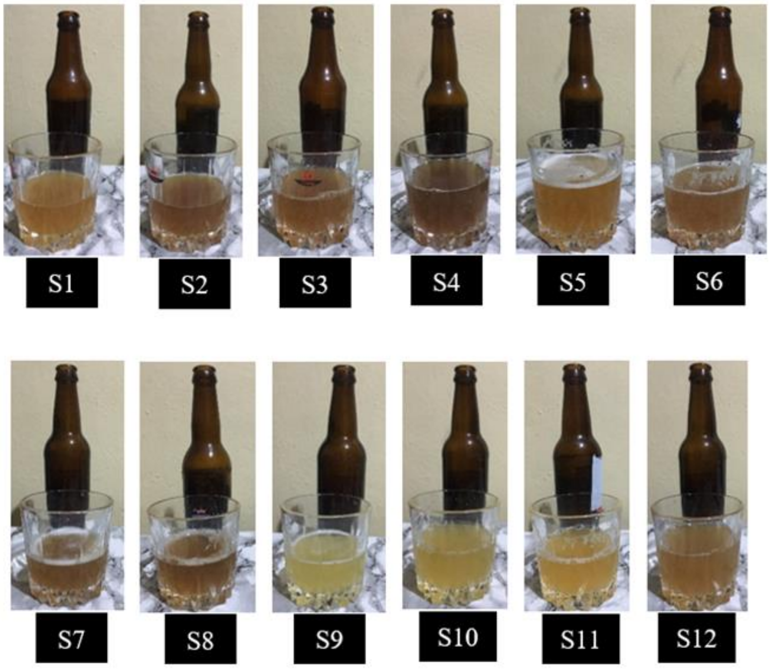

Figure 6: Traditional and improved banana beers produced.

Proximate composition of banana beers produced

The proximate compositions of banana beers produced are presented in Table 3. The moisture contents ranged from 87.95 ± 0.77% to 98.75 ± 0.11%. The products that had the lowest and the highest moisture contents were S8 and S2 with banana, Brix, sorghum, hops, and water formulations of 0.70; 0.10; 0.05; 0.15 and 0.80; 0.20; 0; 0 respectively (Table 2). Initially, only banana juice resulted to increase the moisture content of the beers while other factors resulted to reduce the response except water. However, dilution of banana juice did not result in the highest moisture content banana beer (Ohimain et al., 2016). Hops were observed to reduce the response compared to the other factors (Figure 6). The results of mean separation from ANOVA indicated that there was a significant difference among the moisture contents of banana beers produced at $p<0.05$.

$$\text{Moisture content}=103.67A-111.33B-574.50C+150.78D+195.89AB+3974.25BC \qquad (1)$$

The protein content of banana beers showed interesting results. The bioprocess method resulted to increase the protein content due to malting and mashing of sorghum. This increased significantly the protein contents of the improved banana beer samples. Normally, the overall protein content ranged from 0.01 ± 0.00% to 0.84 ± 0.09%. The word from malted sorghum increased significantly the protein content of banana beers at $p<0.05$. Traditional banana beers were produced with non-malted sorghum flour while improved banana beers were produced with malted sorghum and hop adjuncts. The formulations of banana juice, brix, sorghum/malt, hops, and water for the lowest and the highest banana beer protein contents were S5 and S10, respectively, 0.50; 0.20; 0.05; 0.25; and 0.50; 0.37; 0.03; 0.10. This could have caused by several reasons due to antagonistic or synergic effects among banana beer components. The impact of each single factor played a certain role in the protein content of the beer. However, only sorghum and water had a positive impact on the overall protein content (Figure 7). Specifically, the sorghum malt increased the response, but it was not enough to bring the desired foaming properties. Thus, the protein content, characteristics and origin of beer are linked to the foaming and taste properties of beers (Shale, et al., 2012).

$$\text{Protein content}=0.48A+4.99B-9.00C+4.84D-39.07BD \qquad (2)$$

Fiber content of banana beers produced is presented in Table 3. The values ranged from 0.1 ± 0.00% to 0.595 ± 0.00%. Traditional banana beers showed significantly higher amount of fiber content compared to improved banana beers. The reason for that trend could have come from the malting, mashing, and kilning of sorghum for improved banana beers, whereas banana beer samples were prepared with raw-roasted sorghum. In addition, traditional banana beers were produced with lower dilutions; this imparted them to come up with higher fiber contents. The obtained values of fiber contents were lower than the one obtained from Burukutu by Ogbonna, et al., and South African sorghum beers. However, both banana juice and sorghum contributed significantly to increase the fiber content of the banana beers produced (Shayo, et al., 2000). Generally, the results of ANOVA showed a significant difference between fiber contents at $p<0.05$ for traditionally produced banana beers and improved banana beers (Table 3).

Table 3: Proximate composition of banana beers (%).

Sample	Moisture	Protein	Fiber	Ash	Fat	Carbohydrates
S1	89.61 ± 0.28^{abc}	0.59 ± 0.00^{cde}	0.59 ± 0.00^{f}	0.69 ± 0.01^{f}	0.05 ± 0.00^{a}	8.46 ± 0.25^{g}
S2	98.75 ± 0.11^{f}	0.50 ± 0.00^{c}	0.10 ± 0.00^{a}	0.18 ± 0.00^{ab}	n.d	0.46 ± 0.12^{a}
S3	95.79 ± 0.27^{def}	0.29 ± 0.00^{b}	0.44 ± 0.06^{ef}	0.45 ± 0.00e	0.05 ± 0.00^{a}	2.97 ± 0.21^{cd}
S4	97.77 ± 0.29^{ef}	0.59 ± 0.00^{cde}	0.40 ± 0.00^{de}	0.32 ± 0.05^{cd}	n.d	0.92 ± 0.35^{ab}
S5	97.40 ± 2.02^{ef}	0.01 ± 0.00^{a}	0.10 ± 0.00^{a}	0.08 ± 0.00^{a}	n.d	2.41 ± 2.02^{bc}
S6	93.64 ± 0.10^{cde}	0.75 ± 0.00^{fg}	0.20 ± 0.00^{b}	0.17 ± 0.00^{ab}	0.05 ± 0.00^{a}	5.18 ± 0.08^{ef}
S7	92.75 ± 2.05^{bcd}	0.77 ± 0.05^{fg}	0.29 ± 0.01^{c}	0.40 ± 0.10^{de}	0.34 ± 0.39^{b}	4.25 ± 1.20^{de}
S8	87.95 ± 0.77^{a}	0.63 ± 0.03^{de}	0.50 ± 0.00^{f}	0.43 ± 0.10^{e}	0.02 ± 0.00^{a}	5.85 ± 0.35^{ef}
S9	95.95 ± 1.00^{def}	0.51 ± 0.08^{cd}	0.21 ± 0.01^{b}	0.19 ± 0.01^{ab}	n.d	1.33 ± 1.09^{abc}
S10	89.05 ± 1.00^{ab}	0.845 ± 0.09^{g}	0.50 ± 0.00^{f}	0.28 ± 0.04^{bc}	$0.05 \pm 0 .00^{a}$	6.85 ± 0.50^{fg}
S11	93.95 ± 1.62^{de}	0.61 ± 0.10^{cde}	0.41 ± 0.04^{de}	0.50 ± 0.00^{e}	0.02 ± 0.00^{a}	5.00 ± 0.30^{ef}
S12	92.90 ± 4.80^{bcd}	0.66 ± 0.05^{ef}	0.35 ± 0.07^{cd}	0.13 ± 0.00^{a}	0.04 ± 0.00^{a}	6.50 ± 0.30^{f}

Values are means ± S.D of triplicate determinations, and values with the same superscripts under the same column showed no significant difference at $p>0.05$. S1-S3: Traditional banana beer samples; S4-S12: Improved banana beer samples; n.d: not detected.

The ash content of overall banana beers ranged from 0.08 ± 0.00% to 0.69 ± 0.01%. The formulations that resulted in the lowest and highest amount of ash contents were 0.50, 0.20, 0.05, 0.25 and 0.60, 0.20, 0, 0 of banana juice brix, sorghum/ word, hops and water respectively. Generally, traditional banana beers showed the higher ash content compared to improved banana beers and possibly this could be due to their high level of non-malted sorghum formulations as well as lower dilutions. Malting, kilning, and word preparation stages decreased significantly the amount of ash content in improved banana beers compared to traditional banana beers. Lyumugabe, et al. reported that malting and mashing increase the fermentable materials. Probably the increase in fermentable materials (simple sugars) usually achieved through adequate dilution, and it resulted in lower ash content values of improved banana beers. Thus, the mean separation of results using ANOVA, showed that there was a significant difference in traditional and improved banana beer ash contents at $p<0.05$ (Ssebuliba et al., 2000).

Fat content results for banana beers were reported in Table 3. The values ranged from 0.00 ± 0.00% to 0.345 ± 0.39%. In fact, sorghum was regarded as the influencing factor that increased the amount of fat in banana beers. However, a higher value of fat contents in beers is regarded as a quality defect, due to the reason that fats undergo oxidation which can harm both the taste and shelf life of the beverages. Low fat content results in banana beers were also reported by Dhar. There was a significant difference in the mean separation of fat contents between traditionally and improved banana beers at $p<0.05$. However, the linear mixture model suggested to monitor the fat contents in banana beers was not significant at $p>0.05$.

The carbohydrate content results were presented in Table 3. Carbohydrate contents of banana beers ranged from 0.465 ± 0.12% to 8.46 ± 0.25%. Malting, mashing, and hop adjuncts increased significantly the carbohydrate contents of improved banana beers. Dilution affected positively the overall carbohydrate content in beers by dissolving amylose and amylopectin oligosaccharides, disaccharides into simple sugars. Although starch does not form a true solution with water unless heated in water, during mashing, sorghum malt was heated with some amount of water and this increased significantly the carbohydrate contents in improved banana beers. The higher values for carbohydrate contents were similar to other traditional African sorghum beers. Nout pointed that African traditional alcoholic beverages contain higher amount of carbohydrate content compared to the European beers. Thus, the significant difference was considered at $p<0.05$ between carbohydrate content means of improved banana beers and traditional banana beers (Willaert et al., 2006) (Figures 7 and 8).

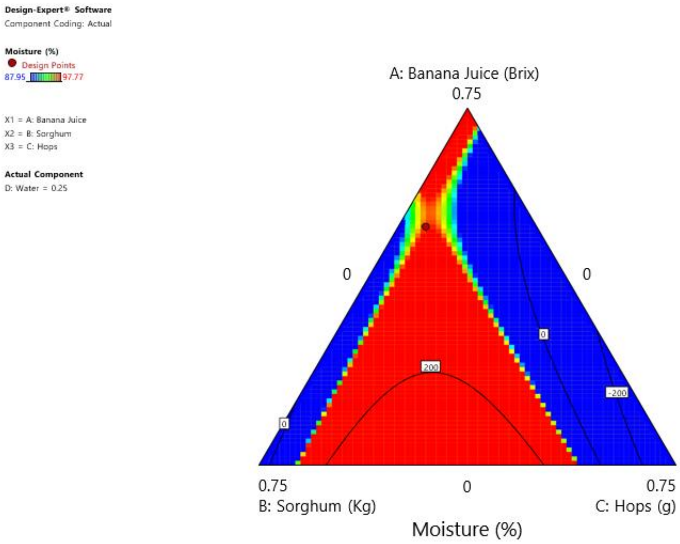

Figure 7: Contour plot displaying the effect of mixture components on moisture content.

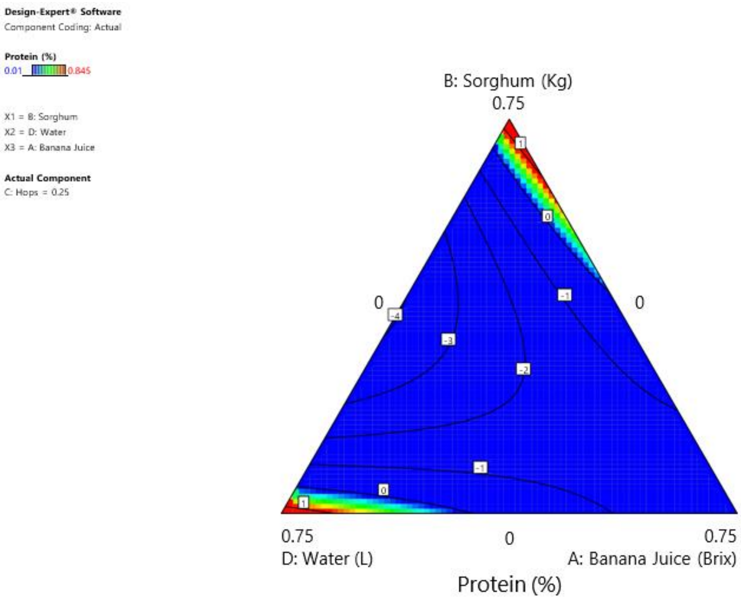

Figure 8: Contour plot displaying the effect of mixture components on protein content.

Physicochemical properties of banana beers produced

Physicochemical properties of the produced banana beers are presented in Table 4.

Alcohol content: The values of alcohol content for banana beers produced were shown in Table 4. The alcohol contents ranged from 3.75 ± 1.06 to 6.12 ± 0.70% Alcohol volume. Right from the start, the sugar content before yeast pitching played a positive or negative response upon the fermentation process (Tables 4 and 5).

Traditional banana beers were not diluted (S1, S2, and S3) as well as S6 and S7. Higher sugar content and gravity in undiluted samples inhibited the yeast growth. This was observed throughout the fermentation process. Unfortunately, undiluted mixtures (S6–S7) from improved banana beers showed good results of alcohol contents. This was a result of mashing of malted sorghum which gave higher amount of fermentable sugars: Maltose, Maltotriose, Sucrose, Fructose, Glucose. Normally, the undiluted mixtures had higher sugar contents (oBrix) than diluted mixtures. Generally, the same issue of yeasts unable to hydrolyze complex sugars was obtained by Navarro. In order to understand the inhibition better, let not forget that any problem that will result in lower sugar conversion will definitely disturb the fermentation process. Willaert and Nedovic reported that glucose is consumed first at 60%, before other sugar molecules are consumed like fructose and maltose, respectively. Dilution of banana juice may provide a suitable way to increase glucose content in fermentable mixtures (Zhan et al., 2010) (Figures 9 and 10).

Table 4: Alcohol content of banana beers produced (%).

Sample	Traditional banana beers			Improved banana beers								
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Alcohol vol.	4.50 ± 0.70^{abc}	4.01 ± 0.41^{ab}	3.75 ± 1.06^{ab}	4.75 ± 0.35^{abc}	5.00 ± 0.00^{bc}	6.12 ± 0.70^{d}	6.08 ± 0.17^{d}	4.25 ± 0.35^{abc}	5.00 ± 0.00^{bc}	5.00 ± 0.00^{bc}	4.75 ± 0.35^{abc}	5.50 ± 0.70^{c}

Values are means ± S.D of triplicate determinations, and values with the same superscripts showed no significant difference at p>0.05. Alcohol Vol: Alcohol content.

Table 5: Methanol content of banana beers (%).

Sample	Traditional banana beers			Improved banana beers								
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Methanol	0.76 ± 0.02^{e}	0.42 ± 0.04^{c}	0.68 ± 0.05^{de}	0.66 ± 0.02^{d}	0.02 ± 0.02^{a}	0.02 ± 0.00^{a}	0.05 ± 0.02^{a}	0.19 ± 0.09^{b}	0.05 ± 0.01^{a}	0.01 ± 0.00^{a}	0.68 ± 0.05^{de}	0.15 ± 0.04^{b}

Values are means ± S.D of triplicate determinations, and values with the same superscripts showed no significant difference at p>0.05.

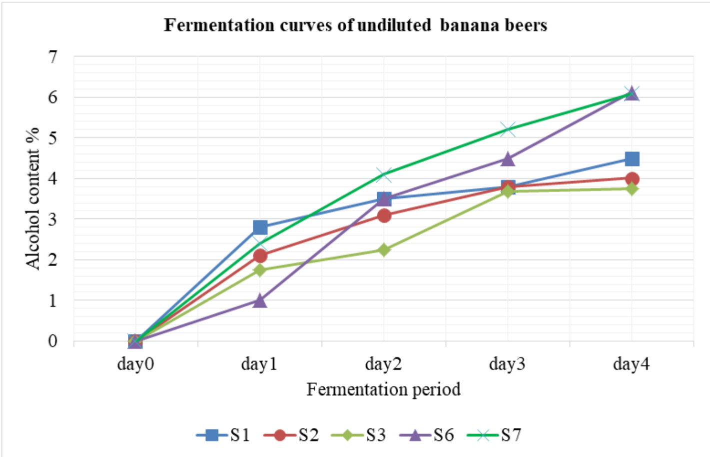

Figure 9: Fermentation process curves (Undiluted mixtures: S1, S2, S3, S6, and S7).

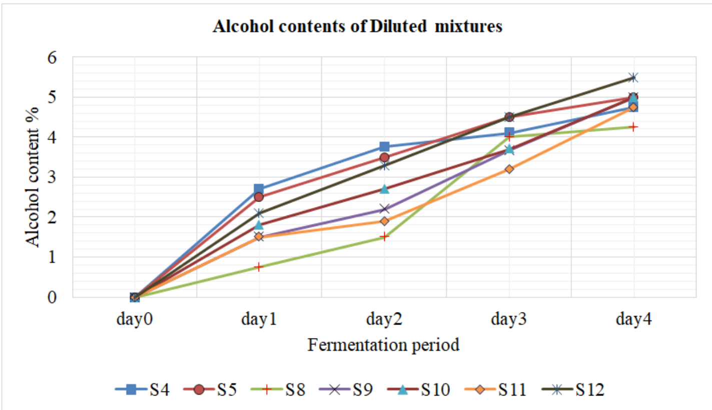

Figure 10: Fermentation process curves (Diluted mixtures: S4, S5, S8, S9, S10, S11, S12).

The information provided is that whenever the starting mixture had high TSS, and it intended up having high osmotic pressure caused by low water activity (aw). Thus, it becomes difficult for yeast to thrive in such environments. The higher TSS in the starting mixture, the higher TSS was observed in the final banana beers (non-fermentable sugar). However, there was no sample observed to have the final TSS of 0° Brix during the fermentation process. This may be due to the fact that the fermentation mixture contains both non-fermentable and fermentable sugars. Furthermore, soluble solids other than fermentable sugars in the mixture resulted to have a certain amount of brix level. There was a linear relationship between TSS and sugar content. Thus, unfermented sugar content was reported as TSS, and it had an impact on other banana beer quality characteristics such as thickness, color, taste, and aroma, the same results were obtained by Mosher and Trantham.

Moreover, the results showed that the overtime sugar content of banana juice reduced as the alcohol content increased. The same results also were obtained for the pH impact on the overall fermentation process. The pH values of the starting mixtures were observed to reduce upon fermentation. In addition, the more acidic the pH tended to be, this had a negative impact on the alcohol production. The suggested linear mixture model to monitor the alcohol content variation in both banana beer types was not significant at $p>0.05$. The values of R^2, adjusted R^2, and adequate precision of 0.93, 0.44, and 3.86, respectively, indicated that the model could not be used to navigate the design space.

Methanol content

Methanol content results of banana beers are presented in Table 5. The values ranged from 0.01 ± 0.00% to 0.76 ± 0.02%. The prevalence of methanol content in traditional banana beers was higher compared to that of improved banana beers. Generally, during the extraction of banana juice, pectinase was used and this could have caused the rise of methanol content. The fact that banana juice obtained from this enzymatic process was not pasteurized might have increased the methanol contents of traditional banana beers. The effect of pectolytic enzymes on fermented beverages has been reported to induce an increase of methanol levels in products like ciders and wines. However, pointed out that yeast strains used during fermentation may play a crucial role to influence methanol production in alcoholic beverages. Furthermore, the study conducted by Ohimain on traditional alcoholic beverages pointed out that methanol production in traditionally fermented beverages can be linked to the activities of pectinase producing yeast, fungi, and bacteria. Thus, these methanol, fungi, and yeast producing organisms might have acted on the tradition banana juice to increase the response to traditional banana beers.

Heat treatment is required in order to deal with methanol prevalence in banana beers. In fact, banana juice must be pasteurized not only to kill possible antagonistic microorganisms to the yeast but also to inactivate some pectolytic enzymes that might be present. Therefore, the methanol contents of both traditional banana beers and improved banana beers showed a significant difference at $p<0.05$. Moreover, the methanol standard by world health organization suggests that the amounts between 6–27 mg/l in beers and 10-220 mg/l in spirits are not harmful, while FDA in USA accepts 0.1% of methanol content. The Reduced Special Cubic model suggested to monitor the amount of methanol in banana beer was not significant at $p>0.05$. The R^2, adjusted R^2, and adequate precision of 0.99, 0.97, and 17, respectively, indicated the adequacy of the model.

Microbial analysis

The microbial counts of banana beers produced are presented in Table 6. The microbial counts showed that traditional banana beers were prone to bacteria contamination compared to the improved banana beers. The sources of contamination of banana beers possibly came from different aspects of raw materials, water, sorghum flour, banana juice, as well as the equipment used to carry out every single operation to achieve successful fermentation. However, both traditional banana beers and the improved banana beers had zero coliform contamination. The microbial contaminations detected from banana beer samples were mainly caused by inadequate pasteurization units obtained from banana juice, word and possibly final banana beers.

Table 6: Microbial counts of banana beers produced.

Banana beer samples	Mean total plate count (log10 CFU/ml)	Mean yeast and moulds count (log10 CFU/ml)	Mean coliform count (log10 CFU/ml)
S1	1.3×10^1	4	n.d
S2	1.9×10^1	4.5×10^1	n.d
S3	5	2.4×10^1	n.d
S4	8	n.d	n.d
S5	n.d	n.d	n.d
S6	n.d	2.0×10^1	n.d
S7	2	n.d	n.d
S8	n.d	n.d	n.d
S9	n.d	n.d	n.d
S10	n.d	n.d	n.d
S11	n.d	n.d	n.d
S12	n.d	n.d	n.d

Values are means of triplicate determinations; n.d: Not Detected; S1-S3: Traditional banana beer samples; S4-S12: Improved banana beer samples.

Yeast and moulds prevailed in both types of banana beers, regardless the type or processing conditions. Yeast may have come from the inoculated yeast for fermentation, and the pasteurization temperature did not kill all. Although the presence of yeast in final banana beers may be regarded as Generally Regarded as Safe (GRAS), they may cause some safety and quality defects. So, this showed that the pasteurization temperature of 85°C for 7 minutes reported was not able to kill all viable yeast and mold cells by in bottle pasteurization. On the other side, mould prevalence was regarded as the result of contamination, favorable pH, and temperature of storage for traditional and improved banana beers. Therefore, banana beer products were reported to last less than two weeks under correct conditions.

Coliforms were not detected in the produced samples. However, the results obtained by Kanyana, et al., moulds, yeast, and coliforms had been reported to be high in artisanal processed banana beers in Rwanda. Nevertheless, the traditional banana beers were produced with safety precautions in order to protect the sensory assessors. For example, some Hazard Analysis and Critical Control Points (HACCP) approaches were used to treat raw materials. This involved using pure water, sorting ingredients, and roasting of sorghum reduced significantly the total coliforms. Thus, roasting temperature, pasteurization, and holding time acted like huddle technology for controlling coliform prevalence in produced banana beers.

Sensory evaluation of banana beers produced

Sensory properties of banana beers are presented in Table 7. The appearance scores of the banana beers produced ranged from 4.30 ± 1.78 to 6.80 ± 1.57. Samples produced with malted sorghum and more inclusions of hops ranked higher in terms of appearance. Traditional banana beers had low appearance. This could be due to lack of malt and poor hydration of carbohydrates to give rise to simple sugars. Heating of natural simple sugars could give a desired color to the beer through the caramelization process.

Table 7: Sensory scores of banana beers.

Sample	Appearance	Taste	Consistency	Aroma	Overall acceptability
S1	5.75 ± 1.12^{cd}	4.85 ± 1.31^{ab}	5.25 ± 0.85^{ab}	5.50 ± 1.76^{abc}	5.05 ± 1.14^{ab}
S2	4.30 ± 1.78^{a}	4.40 ± 1.67^{b}	5.50 ± 1.10^{abc}	5.20 ± 1.82^{ab}	4.90 ± 1.51^{ab}
S3	4.55 ± 1.39^{ab}	4.85 ± 1.31^{ab}	4.90 ± 1.07^{a}	4.95 ± 1.82^{a}	4.60 ± 1.39^{a}
S4	6.10 ± 1.29^{cd}	5.30 ± 1.78^{ab}	4.75 ± 1.65^{a}	6.30 ± 1.45^{bcd}	5.40 ± 1.90^{ab}
S5	4.55 ± 2.04^{ab}	5.25 ± 1.97^{ab}	5.65 ± 1.14^{abcd}	6.15 ± 1.38^{bcd}	5.55 ± 1.82^{ab}
S6	4.30 ± 2.23^{a}	5.05 ± 2.08^{ab}	5.85 ± 1.42^{bcde}	6.00 ± 1.55^{abcd}	5.70 ± 2.22^{abc}
S7	5.15 ± 1.66^{abc}	5.55 ± 2.45^{abc}	5.90 ± 1.55^{bcde}	6.90 ± 1.68^{d}	5.35 ± 2.25^{ab}
S8	5.45 ± 2.25^{bc}	5.65 ± 1.89^{bc}	6.50 ± 1.57^{def}	6.95 ± 1.27^{d}	5.95 ± 1.93^{bcd}
S9	6.80 ± 1.57^{d}	6.85 ± 1.81^{d}	6.50 ± 1.67^{def}	6.40 ± 1.50^{cd}	7.00 ± 1.29^{d}
S10	5.50 ± 1.05^{bc}	6.05 ± 1.43^{bcd}	6.35 ± 1.18^{cdef}	6.45 ± 1.35^{cd}	6.95 ± 1.23^{d}
S11	5.85 ± 0.98^{cd}	6.55 ± 1.27^{cd}	6.95 ± 1.19^{f}	6.00 ± 1.89^{abcd}	6.75 ± 1.33^{cd}
S12	6.00 ± 1.33^{cd}	6.60 ± 1.14^{cd}	6.65 ± 1.59^{ef}	6.65 ± 2.13^{cd}	6.85 ± 1.66^{d}

1: Dislike extremely; 2: Dislike very much; 3: Dislike moderately; 4: Dislike slightly; 5: Neither like or dislike; 6: Like slightly; 7: Like moderately; 8: Like very much; 9: Like extremely; values under the same column with the same superscripts showed no significant difference at p>0.05; S1-S3: Traditional banana beer samples; S4-S12: Improved banana beer samples.

The appearance results of banana beers produced are presented in Table 7. The results were obtained based on assessors to rank the parameters according to color and preferences. Indeed, sorghum played a crucial role to give a desirable color change. Banana beers produced with roasted sorghum flour or roasted sorghum malt were highly appreciated by the assessors. This technology may be adopted to avoid the using of sugar caramel by most of the banana beer/wine producers. Definitely, roasting sorghum is linked to give a good flavor to the banana beers.

The taste for banana beers produced ranked from 4.40 ± 1.67 to 6.85 ± 1.81 as it is presented in Table 7. Generally, 75% of traditional banana beers produced ranked below 5, while 100% of improved banana beers ranked at least 5 or above. This showed an improvement in the taste of banana beers produced with malted sorghum, hops, adequate water dilution, and controlled fermentation. The taste results clearly showed that high sugar content mixtures were not liked by sensory analysts; In addition, hops played a great role in enhancing the taste of improved banana beers.

The consistency scores of banana beers produced were measured by the panelists, and the obtained values ranged from 4.75 ± 1.75 to 6.95 ± 1.19, which are presented in Table 7. Traditional banana beers were ranked low for consistency compared to banana beers produced by the bioprocess fermentation method. This was possibly linked to non-malted sorghum flour and inadequacy dilutions used to produce traditional banana beers. Sorghum grit may have distorted the consistency of traditional banana beers, just because the flour which used it was not finely grinded.

The aroma of banana beers was ranked according to Hedonic scale, and the lowest score was 4.95 ± 1.82 whereas 6.95 ± 1.27 was the highest (Table 7). The least ranked formulation was made by 0.90; 0.10; 0; 0 while the highest ranked formulation was made by 0.70; 0.10; 0.05;0.15 which were banana juice, sorghum flour/word, hops and water respectively. The decrease of aroma profile may be caused by a lack of hops and malt in the formulation rather than it was caused by the high sugar content mixtures. However, yeast, malt and hops were reported to be the major components that result to provide the aroma to the beer.

The overall acceptability scores of banana beers produced were ranged from 4.60 ± 1.39 to 7.00 ± 1.29. The lowest score was from traditional banana beers while the highest score came from improved banana beers with formulations of 0.90; 0.10; 0; 0 and 0.60; 0.20; 0.02; 0.18 respectively. From these formulations, it was clear that the formulation which did not include hops and water dilution resulted in the lowest overall acceptability due to poor processing mixture formulations of some traditional banana beers. Malting, water dilution and adequate use of hops in banana beer production resulted to improve the overall acceptability of banana beers. Therefore, the ANOVA results of the overall acceptability score means showed that there was a significant difference among banana beers produced at $p<0.05$.

CONCLUSION

In this study, traditional and improved banana beers were produced. The bioprocess fermentation method enhanced the quality and safety of traditional banana beers. This could depend on the mixture factors and processing conditions. Malting and mashing of sorghum enhanced both nutritional content and fermentable sugars. Hence, the improved banana beers had higher alcohol content than the traditional banana beers. Protein and carbohydrate contents of improved banana beers gradually increased by malting and mashing of sorghum. However, hops and banana juice did not behave similarly as it was observed from the quadratic equations that showed the effect of factors on those responses. Roasted sorghum and sorghum malt nearly provided the same desired banana beer's appearance. The role of yeast cannot be overemphasized, since they are the ones to ferment the mixture. Nevertheless, sorghum protein had little impact on banana beer's foaming properties as indicated by sensory scores. Thus, in order to obtain a better quality of banana beer, several parameters should be optimized such as pH, temperature, nutrients, and flavor as well as lowering microbial contamination.

Author Contributions

Thierry Uzabakiriho performed conceptualization, experimental design, analysis and result interpretation as well as writing.

Uzodinma Eunice Uche Osinachi performed writing supervision of research, review, and editing.

Acknowledgment

We thank Deutscher Akademischer Austauschidienst (DAAD) for sponsoring this research.

Data availability

All data are included in the manuscript.

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